JET PROPULSION LABORATORY
1983 ANNUAL REPORT

Contents

A description of work accomplished under a contract between the California Institute of Technology and the National Aeronautics and Space Administration for the period January 1 to December 31, 1983.

Cover: This image of a portion of the sky was produced from Infrared Astronomical Satellite (IRAS) data to show the infrared energy emitted by more than 250,000 celestial objects. Each square represents an average of the infrared energy emitted in one small region of the sky. The resolution in other IRAS photographs is about 30 times greater. (See color section.)

JET PROPULSION LABORATORY
California Institute of Technology
Pasadena, California

Director's Message

The year 1983 was one of progress and accomplishment for JPL.

The Infrared Astronomical Satellite mission was a dramatic success and provided astronomical data which has already led to many important publications and which will continue to be analyzed and studied for many years.

In planetary exploration, NASA's planning effort last year laid out a series of missions for future years. NASA's commitment to the plan was confirmed when the start of the Venus Radar Mapper was approved and the initial design phase of a mission to Mars was also approved.

The development and testing of the Galileo spacecraft continued at JPL. Challenging design problems were encountered and solved by JPL scientists and engineers working on this dramatic and difficult mission to Jupiter. At the same time, Voyager flight operations continued with an emphasis on planning for the 1986 Uranus encounter. Several major instrument and shuttle experiments received emphasis within the Laboratory during the year.

I am pleased that JPL remains firmly a NASA center with all work performed under a single NASA contract with Caltech. We are the only NASA center not staffed by Civil Service employees.

During 1983, there were several government examinations of federally funded research and development centers, such as JPL, and our unique position with NASA and our role in the federal government were confirmed as essential for the extremely demanding tasks we perform.

JPL is a part of Caltech, and therefore is committed to the standard of excellence set by that institution. A number of studies at JPL involve Caltech faculty, and Campus research has led to projects undertaken at JPL. These ties are very important, and we seek to strengthen them.

A particularly promising area for Campus and JPL participation was emphasized in 1983—the Advanced Microelectronics Program, described in this report. Here, as in other areas, basic research on Campus is being extended by engineering and application efforts at JPL, leading to exciting mission prospects for future space exploration.

About 25 percent of JPL's effort in 1983 was applied to tasks for other government agencies—primarily the Department of Defense (DOD), about 17 percent, and the Department of Energy (DOE), about 8 percent. The work for DOE decreased slightly, as some of the major projects in alternative energy sources reached a stage where it was appropriate to transfer them elsewhere. The work for DOD increased, as new tasks for the Army were undertaken.

During 1983, the limitations of our facilities were addressed. JPL is overcrowded, undesirably split using leased facilities, and hampered by substandard buildings, some of World War II vintage. In response, the Laboratory has developed a Long-Range Facilities Plan to provide a road map for future new construction requests. Ultimate completion of this plan would consolidate our activities in quality facilities at the main Oak Grove site. In the shorter term, I am pleased that with the support of NASA and the Caltech Board of Trustees, it appears that several significant construction projects will soon be approved and initiated.

Thus, 1983 has been a year of challenge, and the several characteristics of JPL have been examined and confirmed. JPL is

- ☆ *Part of Caltech.*
- ☆ *A NASA center.*
- ☆ *A federally funded research and development center operating under a single contract between Caltech and the sponsoring agency, NASA.*
- ☆ *A multimission laboratory with a primary mission of planetary exploration.*

I look forward to the future with renewed confidence in the great talents of the people of JPL and to opportunities for continued discovery.

Lew Allen
Director

Introduction

There are many facets to the Jet Propulsion Laboratory, for JPL is an organization of multiple responsibilities and broad scope, of diverse talents and great enterprise. It is a community of people united around a common objective: to perform research and development serving the national interest.

The Laboratory's philosophy, mission, and goals have been shaped by its ties to the California Institute of Technology (JPL's parent organization) and the National Aeronautics and Space Administration (JPL's principal sponsor):

- ☆ As part of Caltech, JPL aims for the highest standards of scientific and engineering achievement. Excellence, objectivity, and integrity are the guiding principles of the Laboratory's efforts.
- ☆ As a NASA center, JPL plays a major role in the U.S. space program, in particular that of lead center for the exploration of the solar system. In addition to the planetary program, JPL performs a variety of research, development, and spaceflight activities for NASA and, when directed by NASA, for other government agencies.
- ☆ As a federally funded research and development center, JPL does not compete with private industry, nor does it perform work that should be done in the private sector.

JPL's activities for NASA in planetary, Earth, and space sciences currently account for almost 75 percent of the Laboratory's overall effort. The other 25 percent consists of tasks for the Department of Defense, the Department of Energy, and other government agencies.

JPL built the first U.S. satellite, Explorer 1, and the first planetary spacecraft, Mariner 2, which flew by Venus in 1962. Since then, JPL has sent more than 20 unmanned scientific spacecraft on missions to the moon, Mercury, Venus, Mars, Jupiter, and Saturn.

These missions—the Rangers, Surveyors, Mariners, Vikings, and Voyagers—have vastly increased our knowledge of the origin and evolution of the solar system. We have learned that among the planets of our solar system, life is apparently unique to Earth. Because of these missions, which have allowed comparisons with the histories of the other inner planets, we have also gained a better understanding of Earth—how it has evolved and what its future may hold.

Our understanding of the solar system will be enhanced in the 1980s and 1990s by the missions planned by NASA's Solar System Exploration Committee. The program will emphasize simpler spacecraft, in line with reduced budget resources, but the missions will be demanding and will provide dramatic and important scientific discoveries.

Although there was neither a launch of a planetary spacecraft nor an encounter with a planet by a continuing mission in 1983, the year was one of accomplishment and progress. There were many highlights:

- ☆ The Infrared Astronomical Satellite led the 1983 agenda in *Deep-Space Exploration*. For 10 months, the Earth-orbiting spacecraft revealed one discovery after another, as astronomers for the first time explored the heavens in the infrared. Meanwhile, activities centered on the concurrent development of several flight projects: Galileo to Jupiter; the next legs of the Voyager mission, including encounters at Uranus and Neptune; new Venus and Mars orbiters; and several proposed Mariner Mark II and Planetary Observer missions.
- ☆ In the area of *Telecommunications Systems*, work progressed on the upgrading of the Deep Space Network, through which controllers communicate with distant U.S. spacecraft. The Network is preparing for future

deep-space missions billions of miles away and new responsibilities in tracking Earth-orbiting NASA spacecraft.

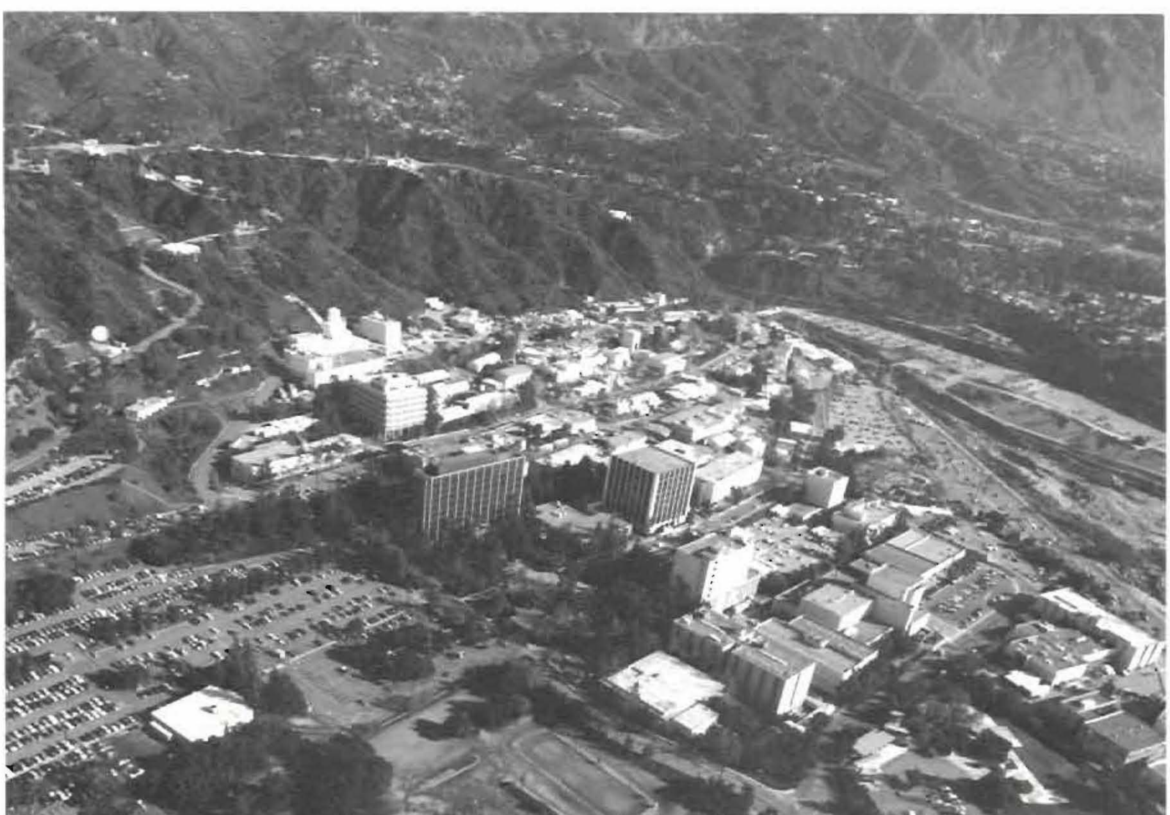
☆ Investigators in *Earth Observations* continued their studies of the oceans (and specific phenomena such as El Niño), the atmosphere, the landmasses, and the polar ice. Development continued on several JPL-designed space shuttle payloads and free-flying scientific missions.

☆ Several new initiatives in *Advanced Technology* were begun. Two areas of focus are microelectronics and optical systems. JPL took steps to provide better coordination of such research, as emphasis on older and more mature technologies gives way to new and ascendant ones.

☆ JPL's *Defense Programs* continued to grow in 1983, with work on several challenging analysis and hardware-development projects. This work, still relatively new to the Laboratory, gives JPL an opportunity to apply and strengthen the technological capabilities developed in the conducting of NASA's space program, while helping to enhance national security.

☆ Shifting federal priorities have caused some reduction in JPL's work in *Energy and Technology Applications*, but researchers nonetheless recorded new progress in the fields of alternative energy (such as photovoltaics), biomedical technology, environmental technology, and aviation.

The following pages detail the events of what was, in summation, another challenging and rewarding year.



Deep-Space Exploration

Mars—that now familiar neighbor of Earth's that has figured so prominently in JPL's past—is an appropriate symbol for describing the state of deep-space exploration in 1983.

In May, Project Viking, the most recent U.S. exploration of the planet, came to a quiet end in JPL's Space Flight Operations Facility. There, engineers tried but failed in a final attempt to reestablish contact with Lander 1, the last operating member of the Viking team of two surface craft and two orbiters.

At the same time, NASA's plans for a first follow-up to Viking—the Mars Geoscience/Climatology Observer—began to take shape. The new mission is part of a proposed series called the Planetary Observers.

Much as Viking symbolized the old way of doing things—a great tradition but one not compatible with current fiscal realities—the Planetary Observers and a second series, the Mariner Mark II, symbolize a new lower-cost approach to exploration beyond Earth orbit.

JPL is planning both series for NASA: Planetary Observers for exploring the inner solar system, and Mariner Mark II missions for investigating more distant targets. The Planetary Observer line will consist of commercial Earth-orbiting spacecraft modified for use in deep space; the Mariner Mark II will be a new class of spacecraft that can be easily reconfigured to meet the needs of specific missions.

In both cases, implementation will follow the recommendations of the Solar System Exploration Committee, a panel NASA formed in 1980 to develop an affordable Core Program of missions to be conducted by JPL through the end of the century.

Key cost-reduction elements include the focusing of scientific objectives, which will in turn simplify mission design; greater use of already existing spacecraft subsystems and hardware; and adoption of a simplified, common mission-operations system. Cost-cutting approaches will also figure in the planning of the No. 1 priority in the Core Program, the JPL-managed Venus Radar Mapper. During the next two decades, these and other continuing and proposed projects are designed to explore every major class of body in the solar system.

JPL also takes a leading role in NASA's other space-science activities, as exemplified by last year's Infrared Astronomical Satellite. This and planned future missions will provide new information about the most remote reaches of our galaxy, and beyond.

The Laboratory's research programs in planetary science and astrophysics are investigating subjects largely paralleling those of the flight missions. Scientists in a broad range of disciplines are supporting missions from the first stages of conception through the final data analysis.

Flight Projects

Infrared Astronomical Satellite

During its 10 months of operation in 1983, the Infrared Astronomical Satellite (IRAS) returned many dramatic scientific findings, including the discovery of solid material orbiting two stars.

IRAS's highly successful mission began with a perfect launch on January 25 from Vandenberg Air Force Base and ended November 21, when the telescope's refrigerant was depleted. (The telescope's focal plane was chilled by superfluid helium to less than 3 degrees Kelvin [−454 degrees Fahrenheit], making IRAS the coldest human-made object to ever orbit Earth.)

The satellite achieved its primary goal: to survey the entire sky and map the location and intensity of objects emitting infrared energy. In addition,

A Deep Space Network controller waits in vain for a return signal from Viking Lander 1. When the craft failed to respond to commands, the Mars mission finally came to an end.

IRAS completed a second survey of almost two-thirds of the sky before its mission ended, thereby adding extra sensitivity to the results.

The catalog of infrared sources now being compiled at JPL from IRAS data is expected to contain more than 250,000 sources, many of them previously unknown.

In addition to the systematic scanning of the sky, which required 60 percent of the satellite's observing time, IRAS made more than 10,000 pointed observations of specific objects and small regions of the sky.

The stars Vega and Fomalhaut, 26 and 22 light-years from Earth, respectively, were each found to possess a ring of solid particles ranging upward from a millimeter in diameter. The findings provide the first direct evidence that solid objects of substantial size exist around a star other than the sun.

Much of interstellar space was found by IRAS to be littered with wispy clouds of dust, termed "infrared cirrus," which are believed to be composed of carbon particles formed in the outer atmospheres of stars and heated by starlight.

IRAS found numerous clouds of molecular gas and dust that are sites of formation of stars like the sun. Data revealed globules consisting of a few hundred solar masses of molecular hydrogen gas that could collapse under their own weight to form stars the size of the sun.

Closer to home, IRAS discovered six previously unknown comets and detected a long dust tail on a comet on which no tail had previously been detected. It also found an object that appears to be an asteroid but approaches closer to the sun than any previously known asteroid.

Data also revealed rings of dust in the solar system in the vicinity of the asteroid belt. Members of the IRAS science team theorize that the rings may be the result of thousands of asteroid collisions over hundreds of millions of years.

IRAS was a truly international effort: NASA built the telescope, the Netherlands constructed the spacecraft, and the United Kingdom planned and executed mission operations. JPL manages the IRAS project.

The Galileo probe is checked during testing at Hughes Aircraft Company. Long years of development will culminate in the probe's brief, 50-minute plunge through Jupiter's atmosphere in August 1988.

Galileo

With launch only about two years away, work continues on Galileo, the first interplanetary mission planned for deployment from a space shuttle.

The spacecraft will be boosted from Earth orbit by a wide-body Centaur launch vehicle after release from a shuttle in May 1986. Galileo's sophisticated dual-spin orbiter will study Jupiter, its magnetosphere, and its major satellites during a 20-month reconnaissance starting when the spacecraft arrives at the planet in August 1988. The spacecraft will also carry a detachable probe. As it descends on a parachute to its ultimate destruction, the probe will conduct a detailed investigation of Jupiter's turbulent atmosphere.

During the past year, a development test model of the spacecraft was assembled for analysis of the spacecraft's structural integrity. Orbiter subsystems also underwent testing in JPL's Spacecraft Assembly Facility before the hardware was removed for updating. The hardware was returned to the facility early in 1984 for reintegration, system testing, and environmental testing.

Because of the intense radiation environment at Jupiter, Galileo engineers have built on the Voyager experience of using radiation-hardened electronic parts. The current design is capable of surviving even more radiation than Voyager, during the nominal 20-month mission.

HUGHES AIRCRAFT COMPANY

A combination of factors has, however, created a new radiation-related hazard to the spacecraft. Continuing analysis of Voyager and earlier Pioneer data has revealed that there are significantly more very high-energy oxygen and sulfur ions trapped in the inner parts of Jupiter's magnetic field than was once thought. While these particles do not present a radiation-damage hazard, they could potentially confuse Galileo's onboard computers by changing values in their memory registers. This process is known as single-event upset, or SEU.

Some of the new-technology parts used in today's spacecraft have been found to be especially vulnerable to SEUs, a fact that is causing concern in a number of NASA and Defense Department programs. Alternate technical solutions to the problem are under study; some parts will be replaced and shielding designs modified to render Galileo safe for its challenging journey.

In other developments, probe subsystem integration was completed at Hughes Aircraft Company, and the probe was delivered to JPL for integration with the orbiter. The retro-propulsion module (RPM) completed its test phase in Germany; the flight RPM was delivered for acceptance testing.

JPL, the overall project manager, is designing and building the orbiter and will direct the flight. The Ames Research Center is developing the probe, while the RPM is being furnished, as a joint international venture with West Germany, by Bundesministerium für Forschung und Technologie.

Voyager

Voyagers 1 and 2 ended the year roughly midway through the second of what will be, with a little luck, four consecutive missions into deep space: the primary mission to Jupiter and Saturn; the current mission to Uranus; a possible follow-on mission to Neptune; and a final mission into interstellar space.

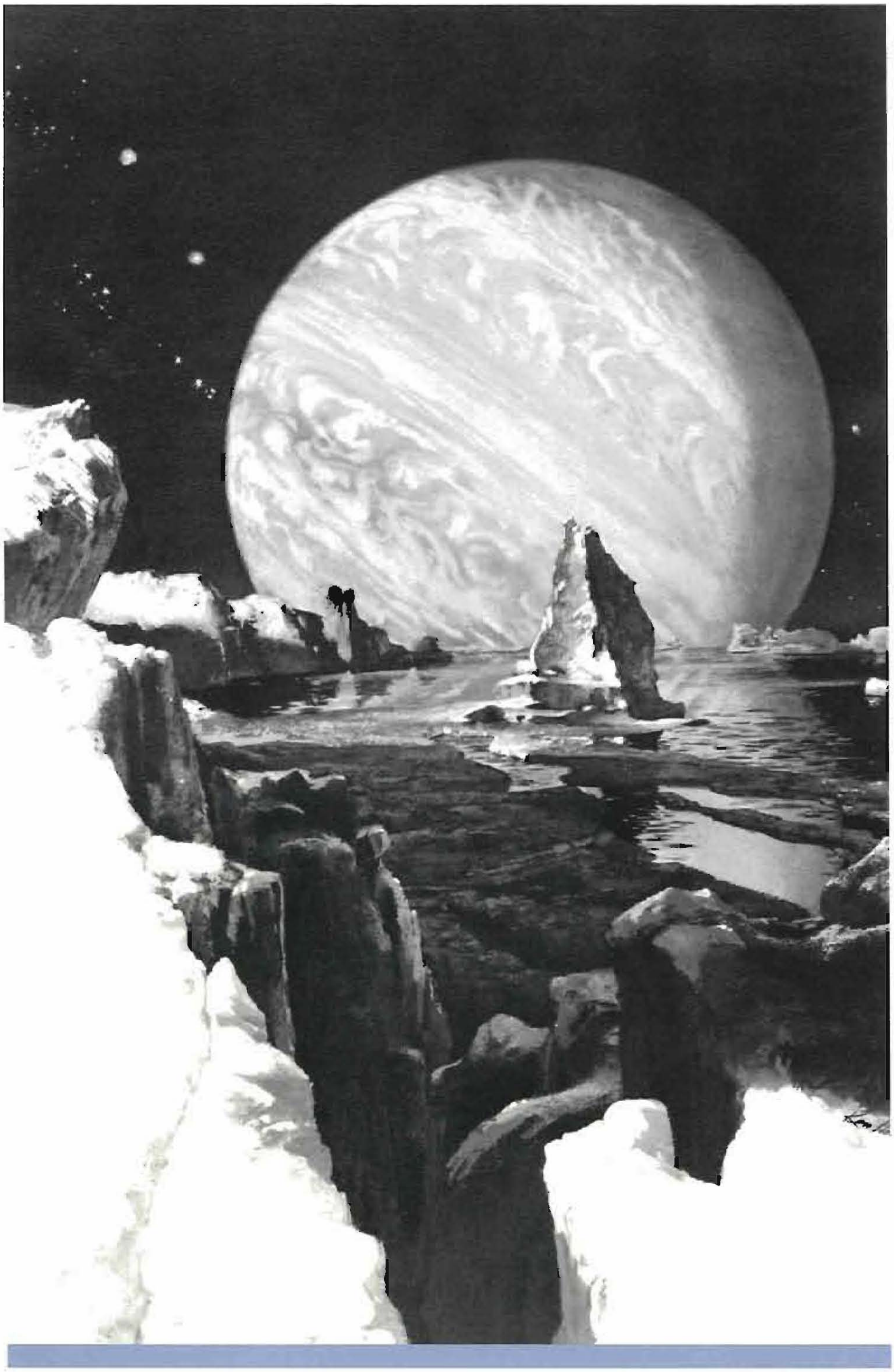
The primary mission carried each spacecraft from 1977 launch through highly successful encounters with Jupiter and then Saturn. The current Voyager Uranus Interstellar Mission began after the last Saturn encounter in late 1981 and will continue through Voyager 2's January 24, 1986, arrival at Uranus.

The status of Voyagers 1 and 2 remained essentially unchanged over the past year. Concern lessened considerably about Voyager 2, on which an actuator mechanism that "stuck" near Saturn continues under some circumstances to impede movement of the science platform. Engineers have achieved a good understanding of the failure and have developed both an in-flight diagnostic tool and a technique that will permit operation even if the platform jams. This improves the prognosis for a Uranus encounter that will be as scientifically productive as the Voyager explorations of Jupiter and Saturn.

Building up from a minimum-level cruise staff in 1983, the project in the coming year will begin an intense period of preparations for the Uranus encounter. Detailed science objectives will be defined, and the construction of the necessary command sequences will follow.

Assuming continued good health, the Voyager Neptune Interstellar Mission will begin in 1986 and continue several months past an August 24, 1989, encounter.

Only component failure could prevent Voyager 1 and then Voyager 2 from reporting their passage through the heliopause. When they cross this plasma boundary—sometime during a period beginning in the late 1990s



In 1989 Voyager 2 will arrive at Neptune, depicted here as it might be seen from its large satellite Triton. The spacecraft may send back data that could show whether lakes or even a shallow ocean of liquid nitrogen exist on this strange moon.

Workers conduct an early phase of testing of the Wide-Field/Planetary Camera, the principal imaging experiment for NASA's Hubble Space Telescope. These tests showed that the instrument met or bettered key performance standards.

and ending after the turn of the century—the Voyagers will formally depart the solar system and enter interstellar space.

International Solar Polar Mission

The final integrated system test for the flight version of the International Solar Polar Mission (ISPM) spacecraft was completed late in the year, as work continued toward a May 1986 launch. JPL is the NASA project manager for the joint U.S./European Space Agency flight.

ISPM is the first and only planned mission to observe the remote polar regions of the sun. All previous solar explorations have been conducted within a narrow zone surrounding the plane in which the planets orbit.

The spacecraft, built by Dornier Systems of West Germany, was placed in storage in Europe after a successful acceptance review in November. The nine science instruments—six sponsored by the United States—were removed and returned to the principal investigators for refurbishment of such items as detectors and computer memories.

Planning at JPL focused on activities leading to a shuttle/Centaur launch—integration of the nuclear power generator (supplied by the Department of Energy), further testing in Holland, and shipment to Kennedy Space Center.

Wide-Field/Planetary Camera

The Wide-Field/Planetary Camera (WFPC), the principal imaging experiment for the orbiting Hubble Space Telescope, successfully completed preliminary calibration and environmental testing at JPL last summer.

Upon completion of the tests—which showed that the WFPC met or exceeded all key science-related performance requirements—the instrument was delivered to Goddard Space Flight Center to support integration activities.

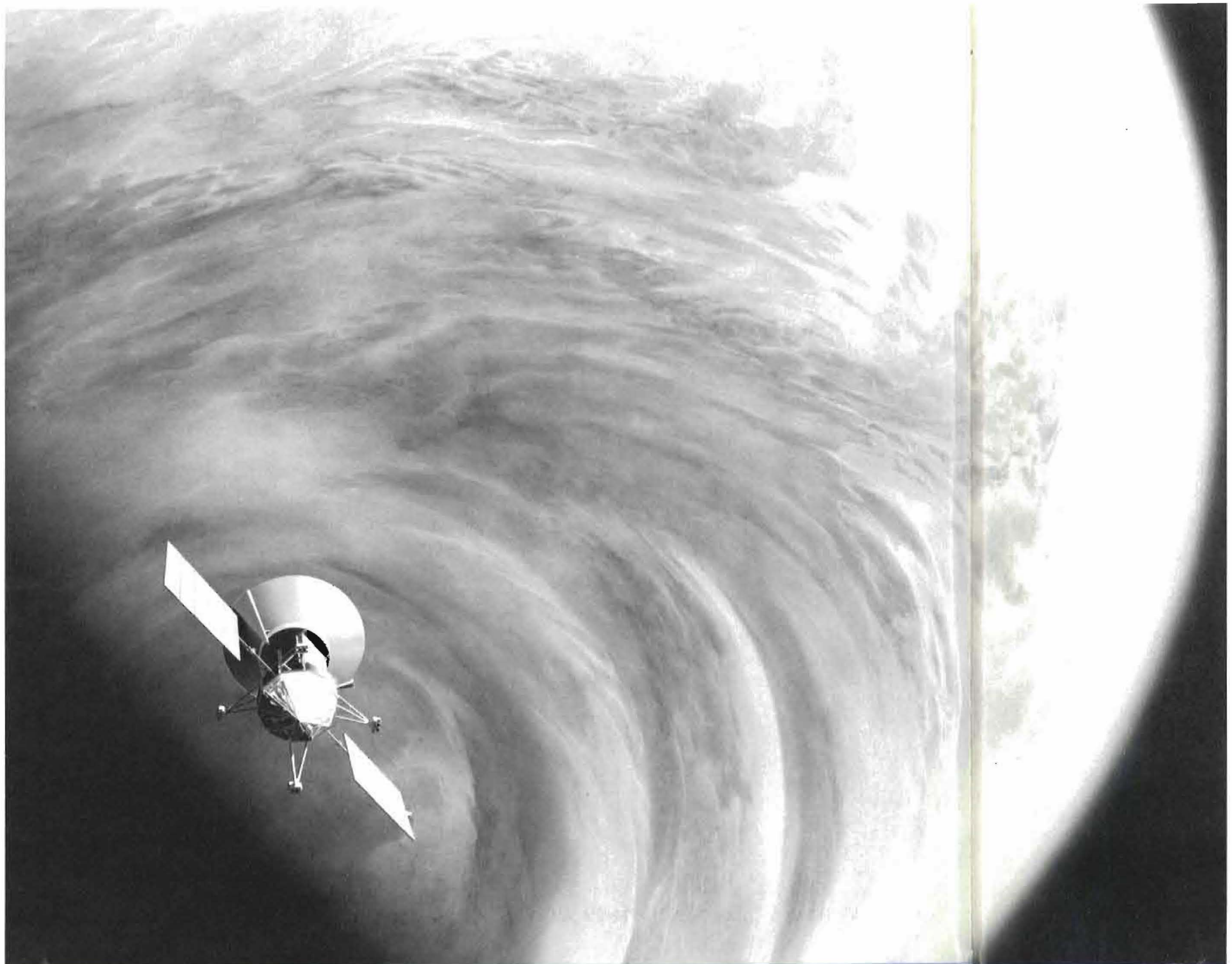
The WFPC contains two complete camera systems. One can record extraordinarily detailed images of individual objects; the other can provide images of a much wider field of view. These important components of the Space Telescope will provide views of the planets and extended objects, such as interstellar clouds, with a clarity unattainable with Earth telescopes.

The cameras have a spectral response stretching from the infrared to the ultraviolet—12,000 to 1,200 angstroms. Forty-eight filters and polarizers will be rotated in front of the cameras to provide spectral information. Each camera will use four charge-coupled devices—solid-state arrays of silicon detectors. The cameras, between them, will image targets ranging from asteroids, comets, and planets in our solar system to galaxies and quasars at the edge of the universe.

After minor cleanup and retesting in spring 1984, JPL will ship the instrument to the main Space Telescope assembly facility at Lockheed Missiles and Space Company in Sunnyvale, California. JPL will continue to support the WFPC through launch and orbital verification in 1986.

Venus Radar Mapper

The Venus Radar Mapper (VRM) mission obtained NASA and congressional approval to become the first planetary new start since Galileo was approved in 1977. JPL and NASA opened contracts with Martin Marietta Corporation and Hughes Aircraft Company in October to begin work on the spacecraft and the radar, respectively.



By year's end, mission science requirements were being defined for issuance in early 1984. The requirements will detail the spacecraft and mission characteristics needed to satisfy the VRM objectives.

VRM's primary task is to gather the data needed to understand the geology and solid-body geophysics of Venus. Because conventional optical systems cannot penetrate Venus' thick sulfuric-acid clouds, VRM will use a synthetic-aperture radar to produce photographic-quality radar images of the planet's surface. Other experiments will measure the radiometric properties of the surface (from which estimates of temperature, composition, and roughness can be deduced), the shape of the planet, and its gravitational field.

VRM will for the first time study the solid body of Venus—its surface and interior—for the kind of detail that earlier U.S. spacecraft have revealed about Mars.

Low-resolution radar data from Earth and the Pioneer Venus Orbiter suggest that Venus has continent-like landmasses, large volcanoes (which may actually have been active in recent years), impact craters, and mountain belts. Additional Pioneer measurements suggest that Venus may have had oceans at one time.

The most recent measurements are being made by the orbiting Soviet spacecraft Venera 15 and 16, which are returning radar images of the surface. Early analysis of the Soviet data indicates that the Venusian surface is unique among the planets and contains information about the solar system's history during periods for which we have little data. The Soviet findings increase the importance of the more complete, higher-resolution coverage that VRM will provide.

VRM will be boosted from shuttle orbit by a Centaur launcher in April 1988. After arriving at Venus four months later, the spacecraft will map at least 70 percent of Venus' surface with a resolution equivalent to one kilometer or better.

Mars Geoscience/Climatology Observer

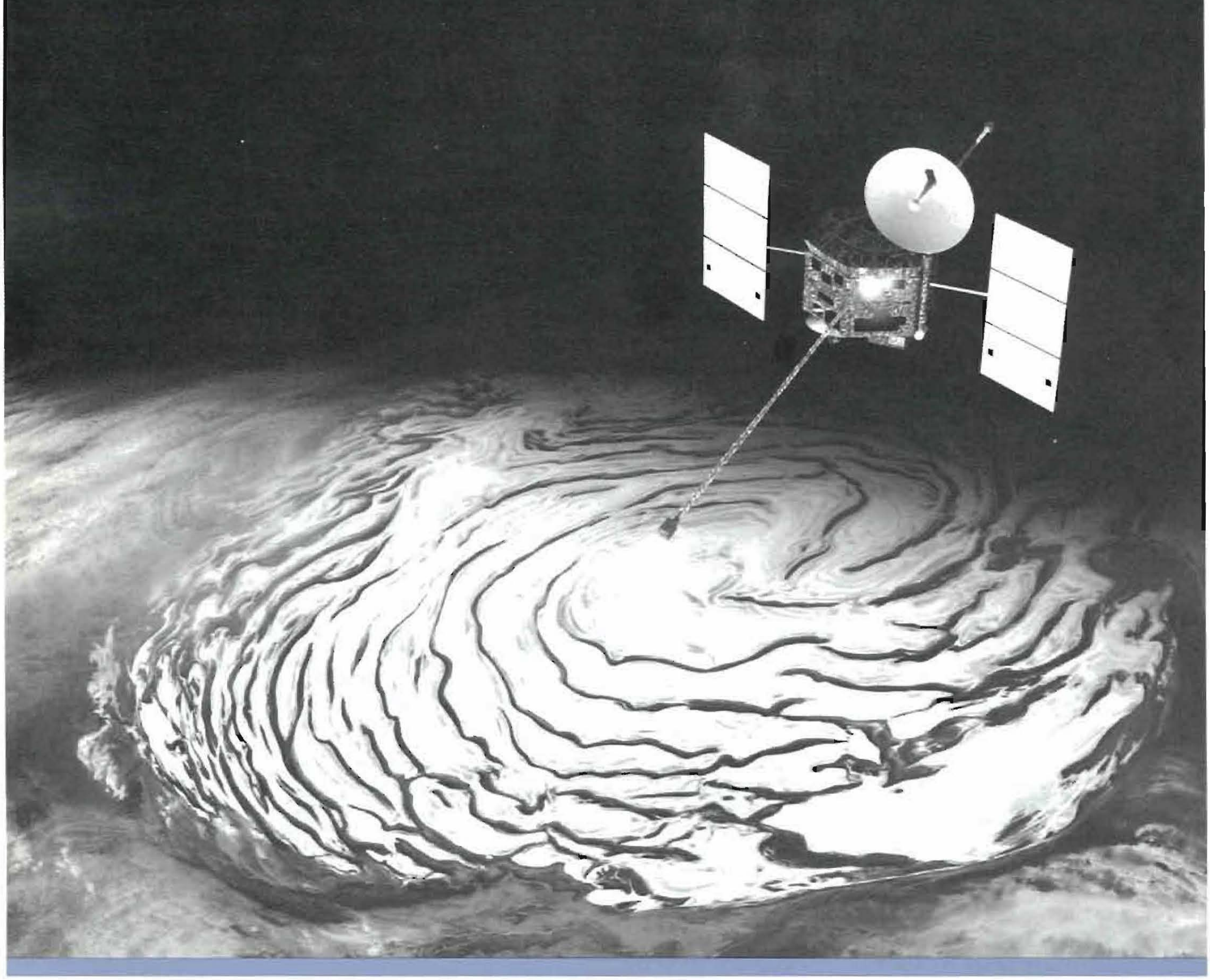
The Mars Geoscience/Climatology Observer (MGCO) is a proposed fiscal 1985 new start. It is being developed as the first of the Planetary Observers, a series of low-cost missions that would send modified Earth-orbiting satellites to explore the inner solar system.

MGCO will be launched in August 1990 using a space shuttle and an upper stage. It will arrive at Mars a year later and, after an initial "phasing" orbit, will enter a mapping orbit that will allow for repeated observations of the planet's surface and atmosphere. Spacecraft performance permitting, the mission could be extended beyond the nominal period of one Martian year (687 Earth days).

Three study contracts with industry, completed early in 1983, verified the feasibility of converting a spacecraft, designed and flown as an Earth orbiter, to a Mars orbiter. The contractors determined that differences between the Earth-orbiting and the Mars-orbiting spacecraft designs would result from several factors, such as a shuttle/upper-stage launch, the interplanetary transit phase, operation at Mars' distance from the sun, and operation in polar orbit at Mars.

A science working group was chartered to advise the project on defining a "strawman" or preliminary study payload and on refining the scientific objectives formulated by the Solar System Exploration Committee. The strawman payload will serve as a guideline in the procurement of a spacecraft bus, or chassis, the major activity for 1984.

The Venus Radar Mapper flies high above our cloud-shrouded planetary neighbor, whose surface lies hidden beneath thick swirls of sulfuric acid.



Mission Planning

Extreme Ultraviolet Explorer

Detailed planning for the Extreme Ultraviolet Explorer (EUVE) is proceeding based on a project start in April 1984.

EUVE, a spin-stabilized Earth orbiter, will be a true explorer in the sense that it will survey the entire sky in almost the last unexplored band of the electromagnetic spectrum between ultraviolet and X-ray radiation: the extreme ultraviolet, which lies between the wavelengths of 100 and 1,000 angstroms.

Astronomers expect EUVE to discover celestial objects with unexpected astrophysical characteristics, much as the Infrared Astronomical Satellite and other spacecraft did during the initial orbital surveys of the other spectral bands.

After launch in 1988, EUVE will use three scanning telescopes to conduct the all-sky survey. A fourth instrument, a deep-survey/spectrometer telescope, will conduct a more sensitive study of a portion of the sky, as well as spectroscopic observations of selected EUV sources detected during the all-sky survey.

JPL will provide overall project management and will manage the flight operations center. The spacecraft will be built by an aerospace contractor selected through competitive bidding. The Space Sciences Laboratory of the University of California, Berkeley, will furnish the instruments, analyze the scientific data, and operate the science operations center.

International Halley Watch

More than 800 professional astronomers in 43 countries and thousands of amateur astronomers around the world joined the International Halley Watch (IHW) in 1983. The network of comet observers is being coordinated by JPL and the University of Erlangen-Nürnberg in West Germany.

The organization focused its efforts on establishing communication links between IHW participants and on developing computer systems, data-collection procedures, and data formats for reporting observations of the comet.

To prepare for the passage of Comet Halley in 1986, astronomers have scheduled a practice observation of Comet Crommelin in early 1984. The "dry run" was designed to test the Halley Watch communications network, through which thousands of observers around the world will report a wide spectrum of observations to the two IHW centers.

Mariner Mark II

NASA and JPL planners determined last year that the first Mariner Mark II mission will be a rendezvous with a comet, coupled to a flyby of an asteroid.

Mariner Mark II is a concept for a new generation of low-cost spacecraft for cometary, asteroid, and outer-planetary scientific missions. The engineering and science requirements are similar enough that nearly all of the same design, hardware, and software for the spacecraft subsystems could be used on each mission.

Scientists and mission planners have recommended that Kopff, a bright and dusty short-period comet, be the subject of the first comet rendezvous. A 1990 launch from a space shuttle would place the spacecraft in the vicinity of Kopff about two years before the comet's closest approach to the sun. The spacecraft would travel with Kopff, in orbit around its nucleus, to study changes in the nucleus, coma, and tail as the comet passes the sun.

In 1990, the Mars Geoscience/Climatology Orbiter will mark our return to the Red Planet. One of several candidate spacecraft is depicted in this artist's rendering.

The Lunar Geoscience Observer, one of several Planetary Observer missions now under study, would examine the permanently shaded regions near the moon's poles.

An added attraction of the Kopff mission is that the trajectory would make it possible to fly past two asteroids before encountering the comet.

A Saturn Orbiter/Titan Probe is the second choice for a Mariner Mark II mission, with launch planned for 1993. The orbiter would conduct a three-year mission with about 30 close encounters of at least eight satellites.

The probe, which may be supplied by the European Space Agency, would study the organic chemistry occurring in Titan's atmosphere. During their flybys, the Voyagers found evidence that processes that may have been important in Earth's prelife atmosphere exist in Titan's atmosphere. The orbiter would perform radar mapping to determine the nature of the surface features.

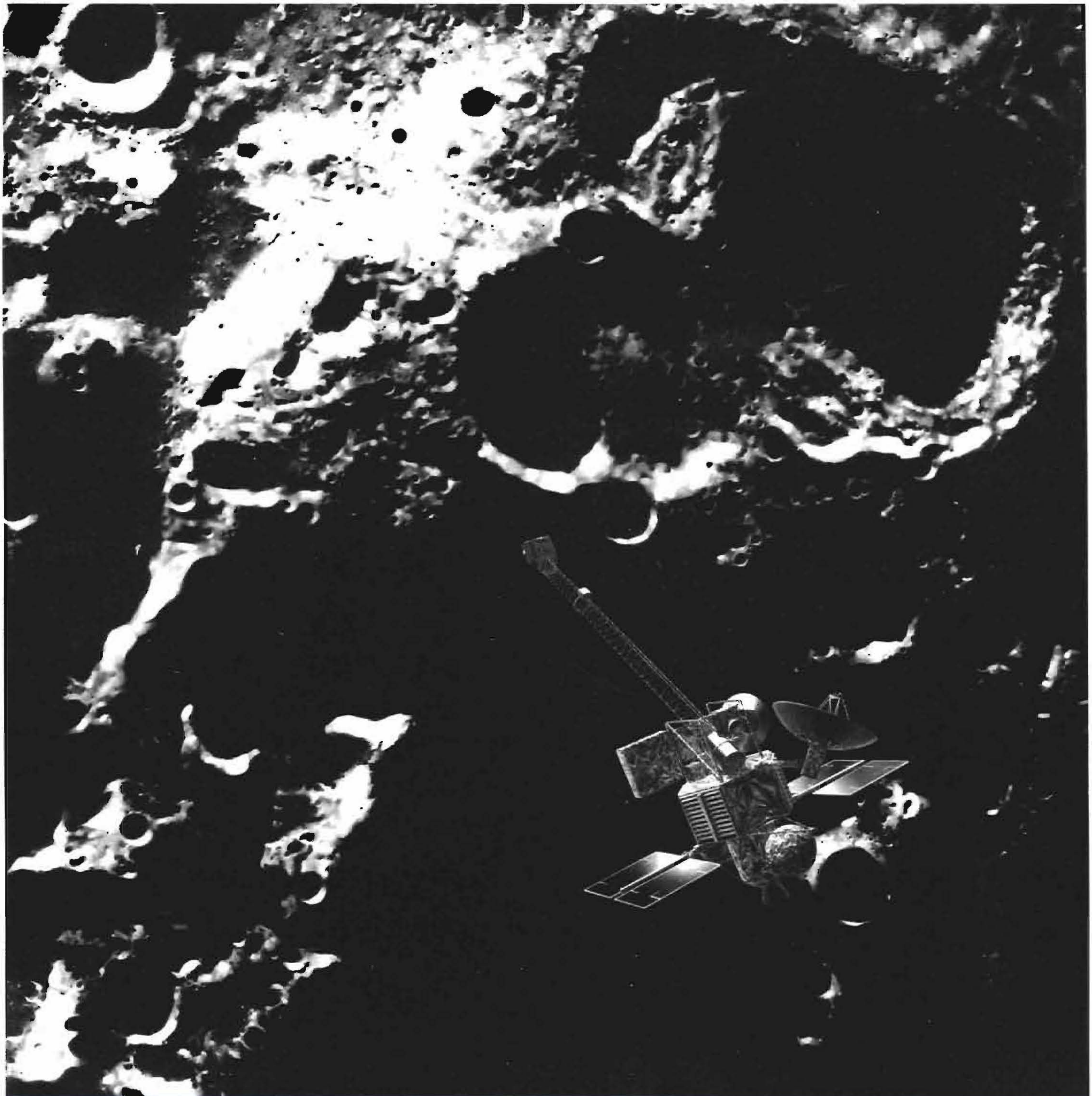
Other proposed Mariner Mark II missions are flybys of and rendezvous with several asteroids in the main asteroid belt, and combination flyby/probe missions to Uranus, Saturn, and Neptune.

Planetary Observers

Mission planning for the new class of Planetary Observer spacecraft began in 1983. The Planetary Observers, of which the Mars Geoscience/Climatology Observer will be the first, will be based on existing satellite designs. The satellites will be adapted to perform scientific missions to objects in the inner solar system.

Among the proposed missions are

- ☆ The Lunar Geoscience Observer, which would be placed in a low-altitude (100-kilometer) orbit to search for water and other volatiles in the permanently shaded regions near the moon's poles and to study the surface in a manner similar to MGCO.
- ☆ The Near-Earth Asteroid Rendezvous, which would encounter an Earth-approaching asteroid such as Anteros. The mission would attempt to determine the composition and surface morphology of these little-known members of the solar system.
- ☆ The Mars Aeronomy Orbiter, which would study the upper atmosphere and ionosphere for daily and seasonal variations. Experiments would measure the escape rates of atmospheric constituents and would measure atmospheric interaction with the solar wind.
- ☆ The Mars Penetrometer Network, which would consist of several missile-like projectiles shot deeply into the Martian surface. Placed in areas around the planet, the probes would establish a global seismic-, soil-, and weather-monitoring network.
- ☆ The Venus Atmospheric Probe, which would build on the results of the Pioneer Venus and Soviet Venera missions to refine our knowledge of the planet's atmosphere. The mission would focus on discovering the precise atmospheric abundances of argon, helium, krypton, neon, radon, and xenon, and would study the sulfur cycle in the lower atmosphere as well.
- ☆ The Comet Atomized Sample Return mission, which would send a spacecraft through the tail or coma of a comet, to capture dust particles and gas molecules in capsules that would then be sealed. The trajectory would be designed to return the spacecraft to Earth orbit, where it would be retrieved by a space shuttle. The mission would be flown in conjunction with a long-term spacecraft rendezvous of the same comet.



Strange surface markings on Jupiter's volcanic satellite Io differ markedly from anything geologists have seen on Earth or on Mars. Years after the Jupiter encounters, Voyager data continue to reveal new findings to scientists.

Low-Cost Operations Study

JPL planners are studying an operations system concept for conducting solar system exploration missions in the 1990s at minimal cost. They hope to find ways of reducing workloads through the application of advanced technology, automation, and improved management standards, as well as through possible changes in project and institutional organizations.

Since more missions of the Planetary Observer and Mariner Mark II classes will be flying simultaneously than is the case with JPL missions of the 1980s, the idea of shared mission operations will also be investigated.

Expert Diagnostic System

An expert diagnostic system called FAITH—Forming and Intelligently Testing Hypotheses—has been developed through the use of artificial intelligence techniques.

Although FAITH holds promise for general use, it will first be applied to automating the detection of anomalies during the Voyager downlink process. An initial scanning compares the measured data to predicted data, allowing FAITH to diagnose the most common errors either in the ground system or on the spacecraft. A knowledge base of Voyager information is now being readied for the task.

Science

Program Direction

Deep-space science activities fall within two distinct programs—planetary science and astrophysics—both of which aim to advance our knowledge of deep space while supporting current and future JPL missions.

Planetary scientists at the Laboratory are particularly interested in the moon, Venus, Mars, Jupiter and its Galilean satellites, Saturn's rings and satellites, comets, asteroids, and meteorites. The program encompasses the disciplines of optical and radar astronomy, chemistry, computer modeling, geology, geophysics, optics, mathematics, mechanics, and physics. Primary tools include imagery, photometry, radiometry, remote sensing, and spectroscopy in all portions of the electromagnetic spectrum.

In astrophysics, topics of interest include the physical processes occurring in the sun and the solar plasma, as well as in stars, galaxies, quasars, and interstellar space. The program comprises six major areas: gravitation, high-energy astrophysics, laboratory astrophysics, radio astronomy, the sun and the solar wind, and research and development of charge-coupled-device imaging instruments.

Relativistic Gravity

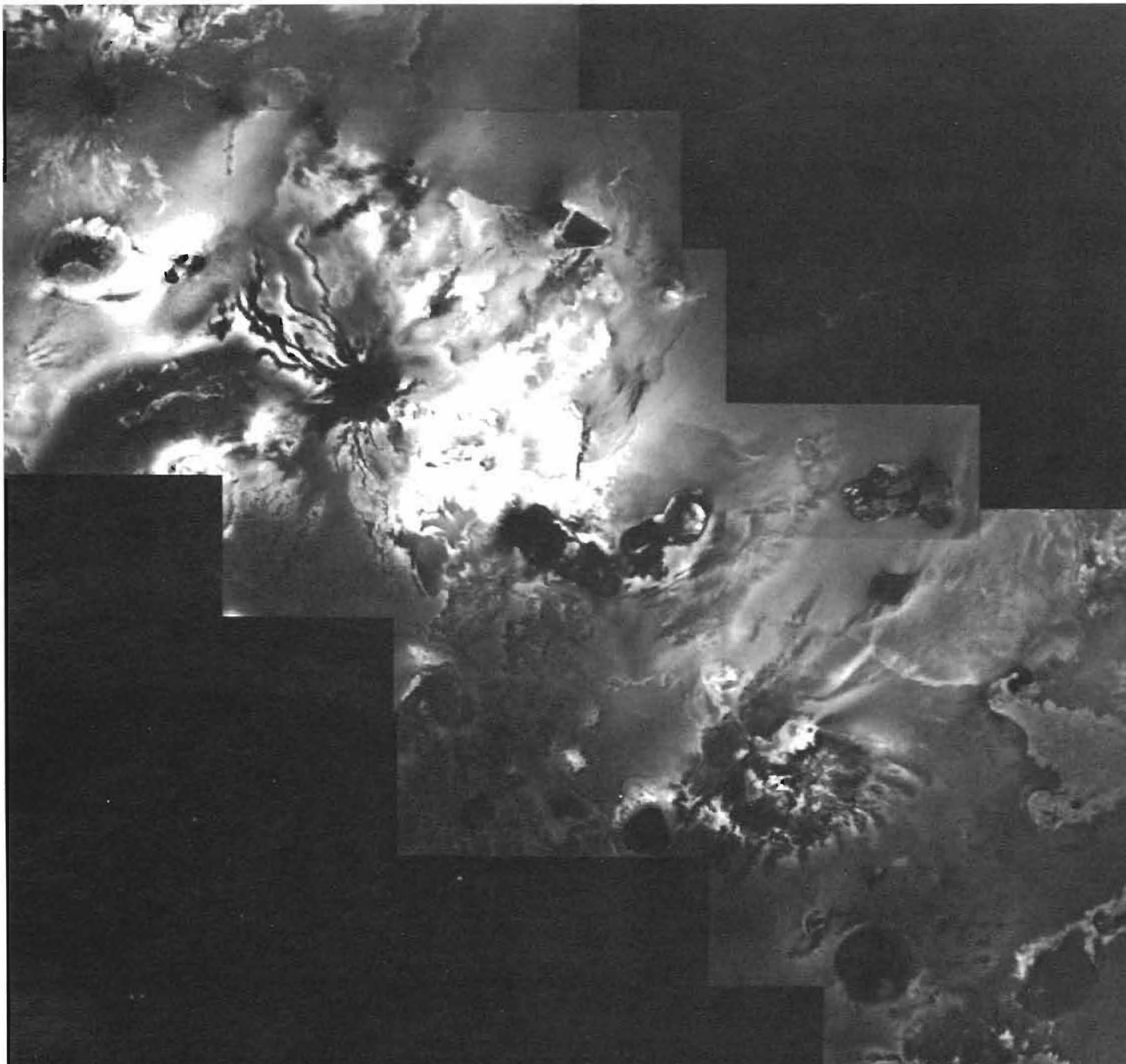
Analysis of data from the Viking Mars landers has allowed JPL scientists to test the hypothesis, suggested nearly 50 years ago by Nobel laureate Paul Dirac, that the gravitational constant, G, is changing as the universe expands. The data also enabled the researchers to test the validity of Einstein's general theory of relativity.

The scientists timed how long it took to send radio signals to the Viking landers and receive a return signal. If the force of gravity produced by the sun had been different from that predicted by Einstein's theory, or if the gravitational constant had been changing, then the orbits of Earth and Mars would have been affected and the radio signal timings would have shown the difference.

No such effects were seen, leading the scientists to conclude that the gravitational constant can be changing by no more than 1 percent every billion years and that Einstein's theory is correct to within one-tenth of a percent.

Asteroid Search

JPL-based observers for the Planet-Crossing Asteroid program continued their systematic search of the sky. One of their discoveries, the Apollo-class asteroid 1983LC, passed a relatively close 5.9 million miles from



PROCESSING BY U S GEOLOGICAL SURVEY

Earth. Another discovery, 1984AB, is unique in being closely associated with the orbit of Mars.

Comet Observations

Astronomers and instruments around the world observed a record 22 comets in 1983, 12 of them never seen before. Six of the dozen discoveries were credited to the Infrared Astronomical Satellite, and six of the 10 returning periodic comets were recovered by JPL's Moving Object Astrometry program through the Palomar Observatory's 48-inch Schmidt telescope.

Two of the new comets approached close enough to Earth to allow JPL observers working with the Deep Space Network to conduct radar studies providing details of the nuclei.

Interplanetary Scintillation

Working with colleagues in California and Japan, JPL researchers employed a technique called interplanetary scintillation to study the solar-wind velocity and density structure very close to the sun. Radio-interferometric observations were made with the Very Large Array in New Mexico. The results will give the most complete description possible of the sun's coronal flow and help planners of future near-sun space probes.

CCD Imaging of the Outer Planets

JPL and University of Arizona astronomers obtained some of the highest-resolution images ever recorded of Uranus and Neptune. They also collected data that will allow more detailed searches for new satellites of the most distant planets. The observers used the instrument-definition charge-coupled device from the Wide-Field/Planetary Camera, in combination with a planetary coronagraph, at Las Campanas Observatory.

Primitive Meteorite

JPL's work on the Qingzhen chondrite from China has demonstrated that it is, thus far, the most primitive known unequilibrated meteorite made of enstatite. Electron microprobe and scanning electron microscope studies of the object have provided major clues to the origin of reduced matter in the solar system.

HEAO Findings

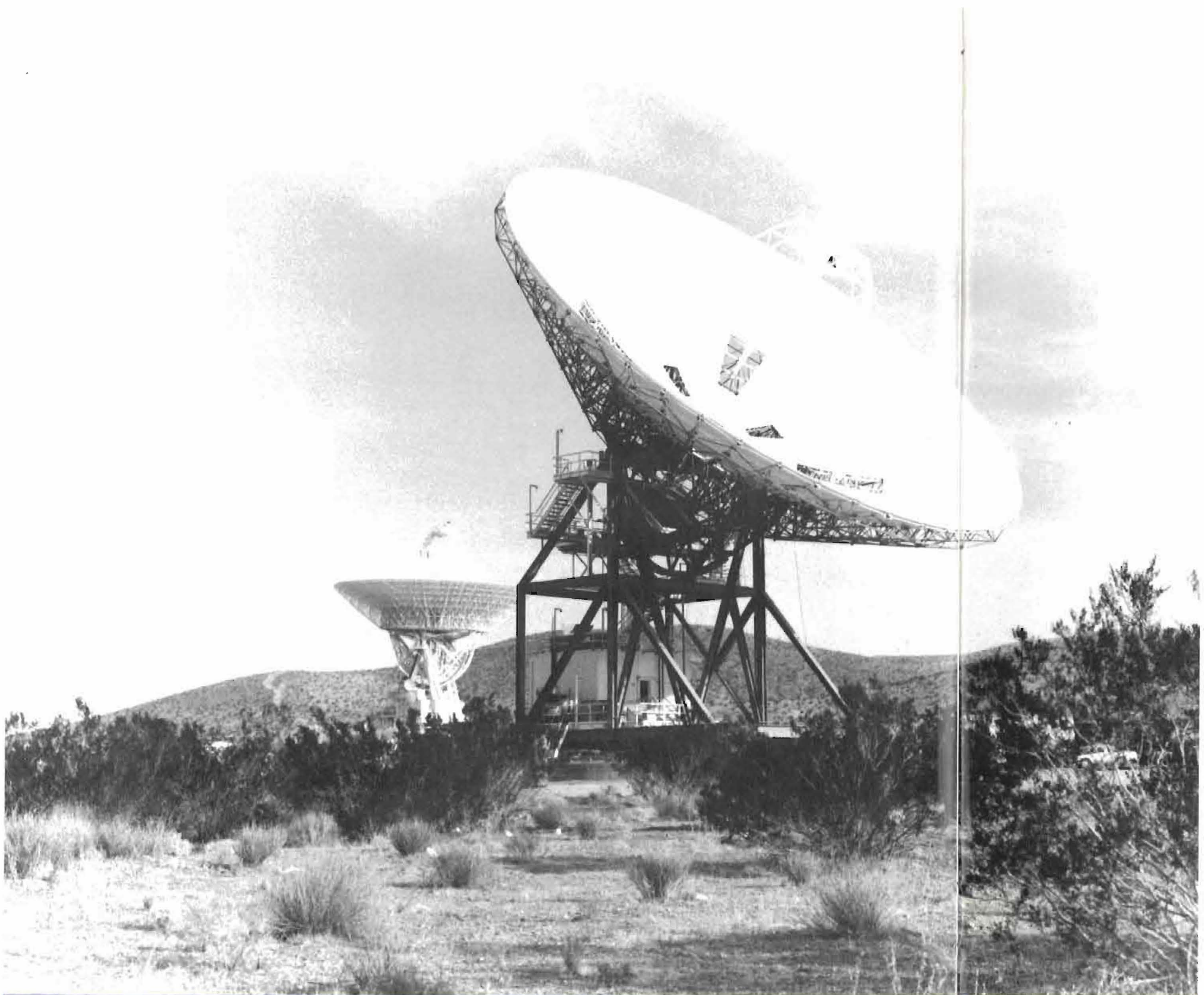
JPL's gamma-ray spectrometer aboard the third High-Energy Astronomical Observatory (HEAO-3) spacecraft revealed the existence of radioactive aluminum-26 in the present interstellar medium. Since the isotope has a mean life of only a million years, its presence lends strong support to contemporary theories that heavy elements are produced from hydrogen in supernovae and novae.

The HEAO-3 instrument also detected the gamma-ray emission from the bizarre galactic object known as SS 433. Previous optical observations had revealed the presence of two oppositely directed jets of material being ejected from a central source (possibly a recently formed neutron star or black hole) at 26 percent the speed of light. The HEAO-3 measurements provide important information on the energetics and chemical composition of the jets.

Geotail Measurements

After four years in interplanetary space, the third International Sun-Earth Explorer (ISEE-3) spacecraft was directed into Earth's magnetic tail before being maneuvered for a 1985 flyby of Comet Giacobini-Zinner. The JPL vector helium magnetometer aboard ISEE-3 made the first magnetic-field measurements in the geotail at distances of two to four times the orbit of the moon. Initial results show that the geotail retains many of its near-Earth properties far beyond the orbit of the moon.

IRAS-Araki-Alcock was one of six comets the Infrared Astronomical Satellite found in 1983.



The Deep Space Network (DSN) serves as a worldwide system for communicating with U.S. spacecraft exploring the solar system. As the link between the spacecraft and controllers on Earth, the Network is responsible for receiving data returned from deep space and for the transmission of instructions to the spacecraft.

Since its establishment in 1958 in support of the first U.S. satellite, Explorer 1, the DSN has grown to include nine deep-space communications stations; a Network Operations Control Center and ground facilities at JPL; and ground communications linking all locations.

The stations are located in three multistation Deep Space Communications Complexes spaced at widely separated longitudes—near Goldstone, California; Madrid, Spain; and Canberra, Australia—so that spacecraft traveling beyond Earth orbit are never out of view.

Each complex is equipped with a 64-meter-diameter antenna station; in a continuing major activity, the antennas are undergoing improvement and expansion to 70 meters. The smaller antennas at each complex—26 and 34 meters—will eventually be joined by new 34-meter high-efficiency antennas.

Although the focus will remain on deep space, the Network is undertaking new responsibilities for spacecraft closer to home. Under negotiations completed in 1983, the DSN will provide emergency support to NASA missions that normally would communicate through the Tracking and Data Relay Satellite System (TDRSS) now being placed in operation. The DSN will also provide routine support to Earth orbiters not compatible with the TDRSS.

This large number of missions, both near-Earth and deep-space, represents a radical departure from the past, when the Network supported only a small number of deep-space missions.

JPL's Office of Telecommunications and Data Acquisition (TDA) will oversee the implementation of these new DSN duties, while managing continuing studies in radio science, ground-based radar and radio astronomy, geodynamics, and the Search for Extraterrestrial Intelligence. TDA also manages the Laboratory's institutional Computing and Information Systems Office.

Mission Support

Operations

In 1983 the DSN continued to support Voyagers 1 and 2 and seven Pioneer and Helios spacecraft, which are providing general science and engineering data.

Additionally, the Network supported Viking Lander 1 until the declared end of the mission in May; controllers had made many attempts to communicate with the vehicle after it ceased to respond in November 1982. The DSN was also instrumental in helping NASA recover from launch problems with the first Tracking and Data Relay Satellite.

Voyager. The DSN provided a significant amount of station support for flight-data-system testing, spacecraft calibrations, and other special tests in 1983. Many of these tests were conducted in preparation for the Voyager 2 Uranus encounter in January 1986. The Network continues to receive general science and engineering data from both spacecraft during their cruise phases. It has also started uplinking commands at higher power on a regular basis because of the increased Voyager spacecraft distances.

Two antennas share a lonely vigil in California's Mojave Desert, where they help provide a critical link between controllers and distant spacecraft.

Pioneer. DSN tracking of the Pioneer missions, which are managed by NASA's Ames Research Center, continued in 1983. Pioneers 10 and 11 continued to return data on cosmic rays, solar-wind plasma, and magnetic-field variations from previously unexplored regions of the outer solar system.

Pioneer 6, the world's oldest functioning spacecraft, has exceeded 18 years of operation and continues to return solar weather data from its orbit between Earth and Venus. Pioneer 12 continues in orbit around Venus, gathering data that will contribute to future missions to that planet.

Networks Consolidation Program

The Networks Consolidation program and the Mark IVA project made considerable progress in 1983. The goal is to centralize control of Network subsystems and to increase the DSN's tracking, data-handling, and operations capabilities.

Manufacture of two new 34-meter high-efficiency antennas was completed and assembly and erection begun both at Goldstone and Canberra. A third start is planned for Madrid in 1985. The new, more efficient design embodies a novel wheel-and-track azimuth rotation system that assures uniform loading and hence uniform wear under varying wind and usage conditions.

Installation of the first centralized signal-processing center began at Goldstone in late 1983. It will be used initially as a demonstration facility to prove out the centralization concept for all Deep Space Communications Complexes. A local-area network will provide centralized monitoring and control, as well as data transmission between subsystems.

Work continued on relocation and reassembly of two 26-meter antennas from NASA's Goddard Spacecraft Tracking and Data Network, the equivalent of the DSN for tracking satellites and spacecraft in Earth orbit. The process was completed in Australia and begun in Spain. Full integration into the DSN is planned for 1987.

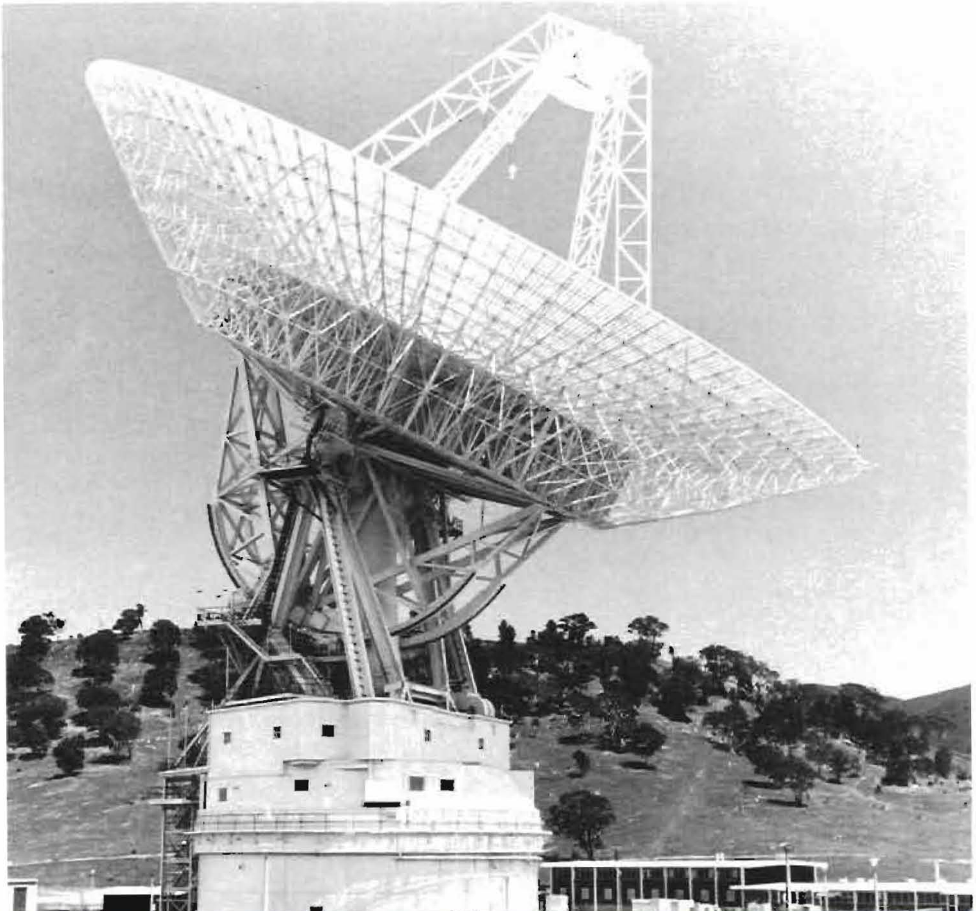
Goldstone Antenna Rehabilitation

The detection of small cracks led to the decision last year to replace a large portion of the concrete in the pedestal of the 64-meter antenna at Goldstone. Over the last 20 years a small amount of aggregate had chemically reacted with the cement in a way that caused micro-cracks in the concrete. The result was a deterioration of the concrete's stiffness to the point where the azimuth thrust bearing could not operate properly.

The 6-million-pound antenna structure was raised about five-eighths of an inch by hydraulic jacks, and three sets of steel support columns were placed underneath. With the weight of the antenna transferred from the concrete pedestal to the external support structure, the hydraulic bearing components were removed, thus clearing the pedestal for replacement of the concrete. A ring (about 6 feet wide and 7 feet deep) around the 80-foot-diameter upper edge of the pedestal is being replaced with high-quality concrete.

At the same time workers are refurbishing the steel runner upon which the three hydrostatic bearing pads ride. The 11 segments making up the runner—each of which is 5 inches thick, 44 inches wide, and 8 tons in weight—were, where necessary, sanded by hand to ensure flatness within four-thousandths of an inch.

The concrete work was expected to be completed in early 1984. After reinstallation and testing, the antenna was scheduled to be operating in June 1984, a year after being taken out of service.



More than 200 feet across and 23 stories tall, this antenna in Australia is one of three in the DSN undergoing expansion in anticipation of Voyager encounters at Uranus and Neptune.

Arraying for Voyager at Uranus and Neptune

The forthcoming Voyager 2 encounters with Uranus in 1986 and Neptune in 1989 present a challenge to deep-space communication. During the Neptune encounter, the Voyager X-band radio signal will be less than one-tenth as strong as it was at Jupiter in 1979 and less than one-half as strong as it will be at Uranus in 1986.

Data compression and a new data-coding system, which has been programmed into the spacecraft's computer by means of commands from Earth, will make up for part of the decrease by allowing imaging to be stored and transmitted at lower data rates. To further offset the decrease, the DSN plans to install a new 34-meter high-efficiency antenna at Madrid and to enhance the Network's three 64-meter antennas. The latter antennas will be made more efficient and will be expanded to 70 meters to effect a better than 50 percent increase in the signal.

Together, these improvements will provide continuity to the general science data gathered by Voyager and a near-doubling of the expected number of images obtainable at Neptune encounter.

A further increase in telemetry performance will be in place by Uranus encounter when the Parkes Radio Telescope in Australia is reactivated for arraying with the DSN antennas near Canberra. NASA and JPL are seeking a similar arrangement with the National Radio Observatory's Very Large Array near Socorro, New Mexico, where preliminary engineering work has been carried out. A third ar-

rangement is being considered with the Japanese Institute of Space and Astronautical Sciences for arraying its new 64-meter antenna with the Australian antennas.

These special arrangements with non-DSN antenna facilities would increase the potential image return from Neptune by another 50 percent.

Mission Planning

Deep Space

All complexes conducted successful tests with the third International Sun–Earth Explorer spacecraft. The spacecraft, renamed the International Cometary Explorer, has been redirected on a flyby trajectory to Comet Giacobini-Zinner. The tests verified the DSN's ability to support the mission through a September 1985 encounter.

The Galileo project has elected to make early use of DSN facilities in its spacecraft integration and test phases. The integration and testing of Galileo in a "flight-like" environment will promote the early identification of problems inherent in the end-to-end telecommunications system, while exposing crews to the operations environment they will experience during the mission.

Implementation was begun to provide an L-band receiving station on 64-meter stations to support the international Venus Balloon and Venus–Halley missions. The DSN will form the core of an international interferometric radio navigation network for the balloons.

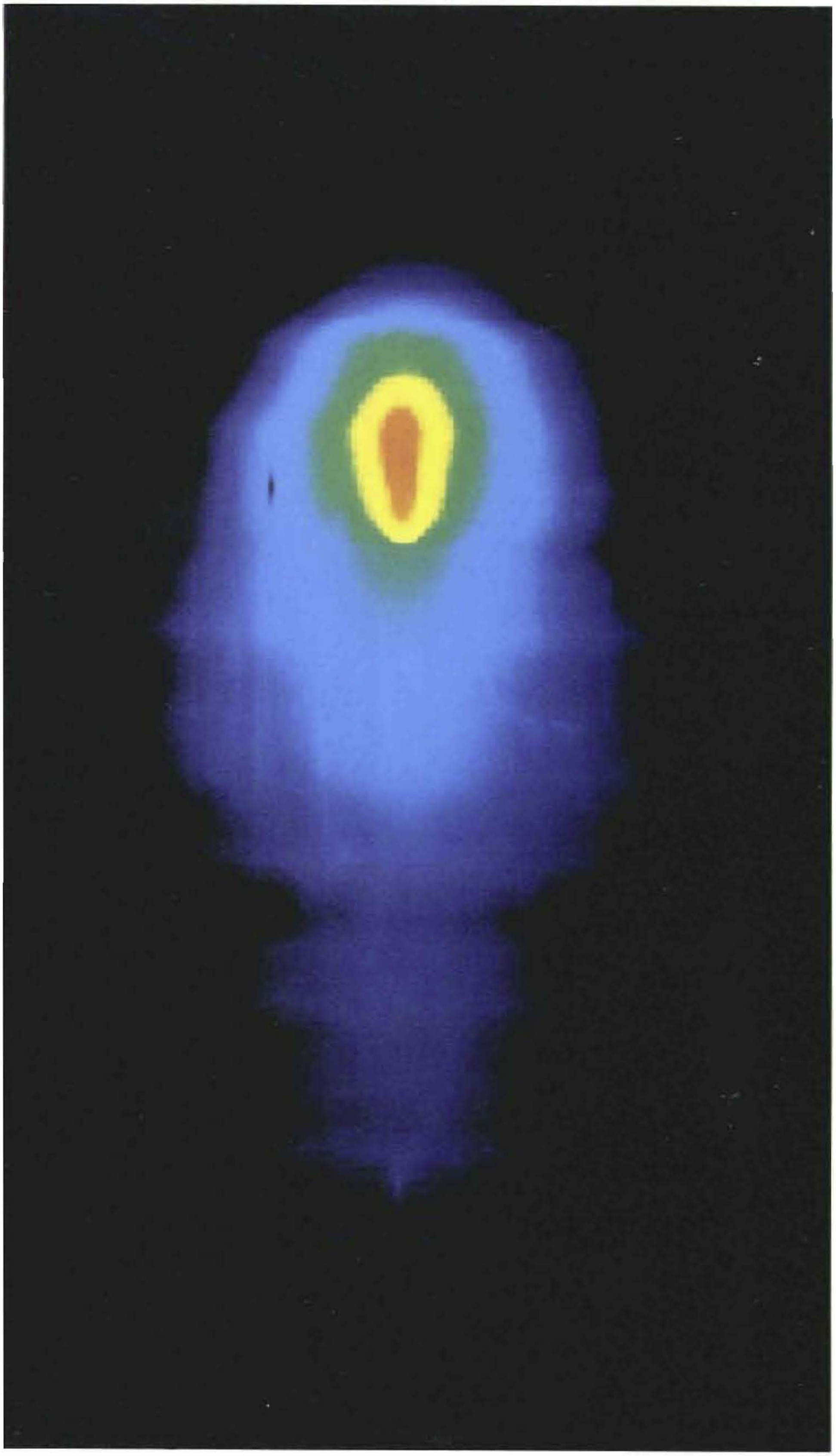
Earth Orbiters

The DSN has completed arrangements in support of NASA's three Active Magnetospheric Particle Tracer Explorer (AMPTE) spacecraft. The interfaces include real-time telemetry and commanding, with operations centers in West Germany and the United Kingdom and at JPL. Testing has begun in anticipation of the three AMPTE launches in August 1984 and later releases of experiment canisters that will require critical data support from the DSN.

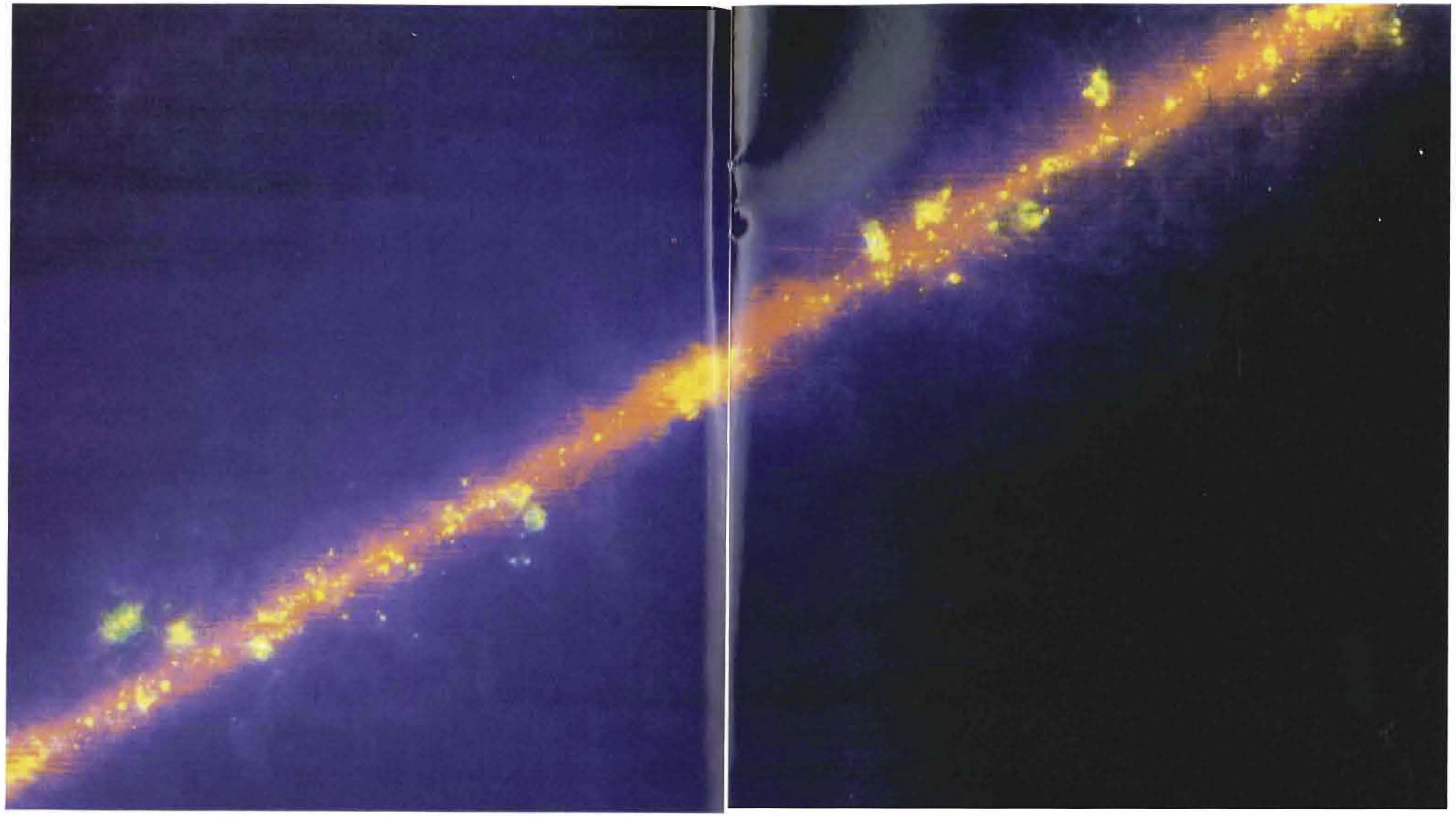
The Operations Control Center at JPL serves as the central switchboard for the DSN. Here, engineers maintain around-the-clock contact with deep-space craft.

Selected Color Images

One of the first IRAS findings was the discovery of Comet IRAS-Araki-Alcock (named after IRAS and co-discoverers Genichi Araki of Japan and G.E.D. Alcock of Great Britain). This infrared image of the comet (right) was taken by IRAS on May 8, 1983, and shows the coma surrounding the nucleus. The coma covers an area about the size of Earth, while the nucleus is only about a half-mile in diameter. Red represents the warmest material, and blue the coldest.

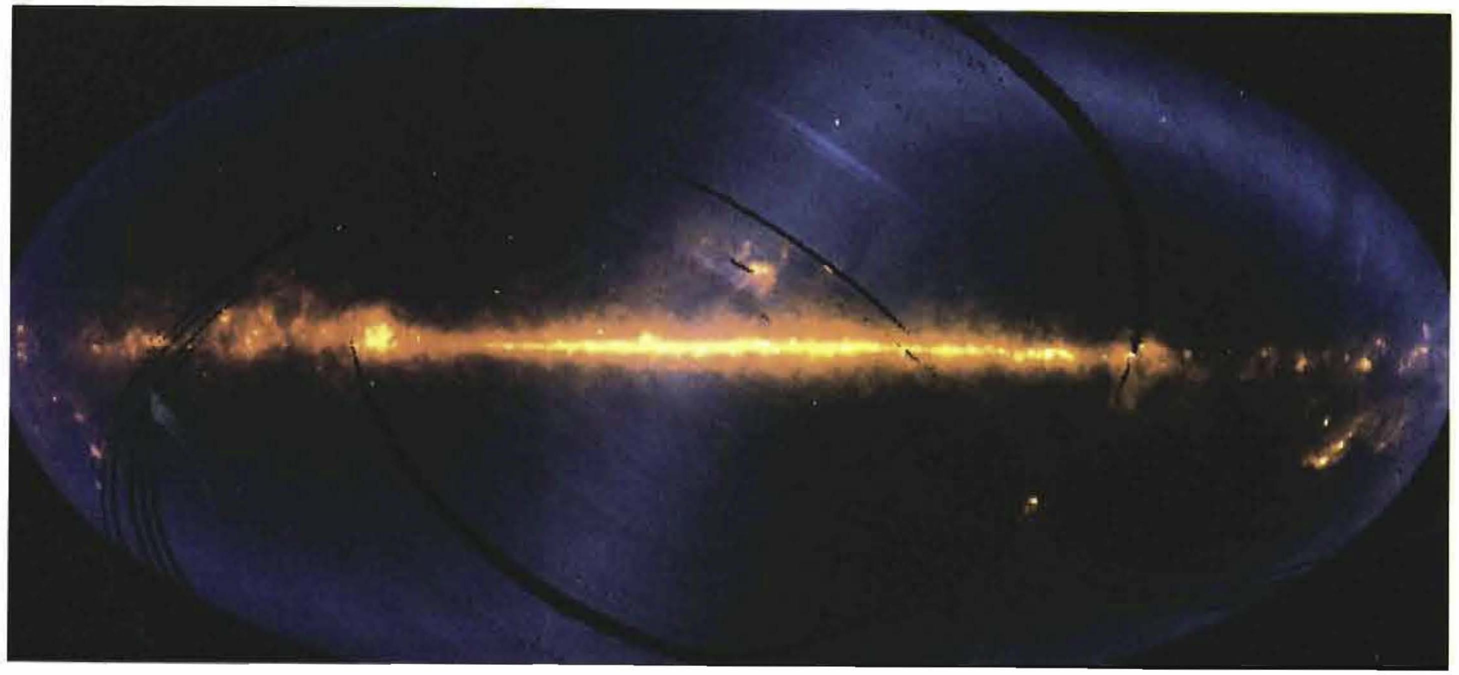


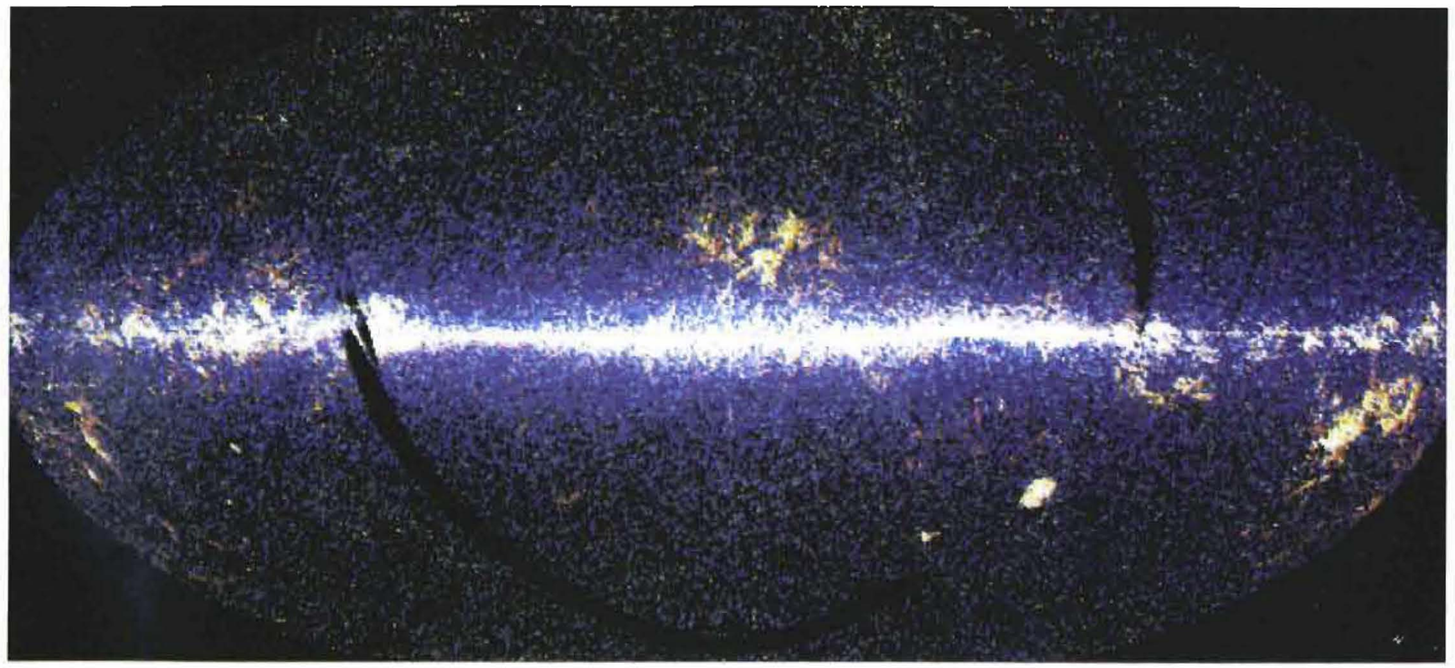
IRAS viewed our galaxy, the Milky Way (right), and found giant clouds of interstellar gas and dust heated by nearby stars. Some of the clouds are warmed by newly formed stars embedded within the clouds, and some are heated by nearby massive, hot, blue stars that are tens of thousands of times brighter than our sun. Red areas represent regions dominated by cold gas and dust. The large yellow bulge near the middle is the center of the galaxy.

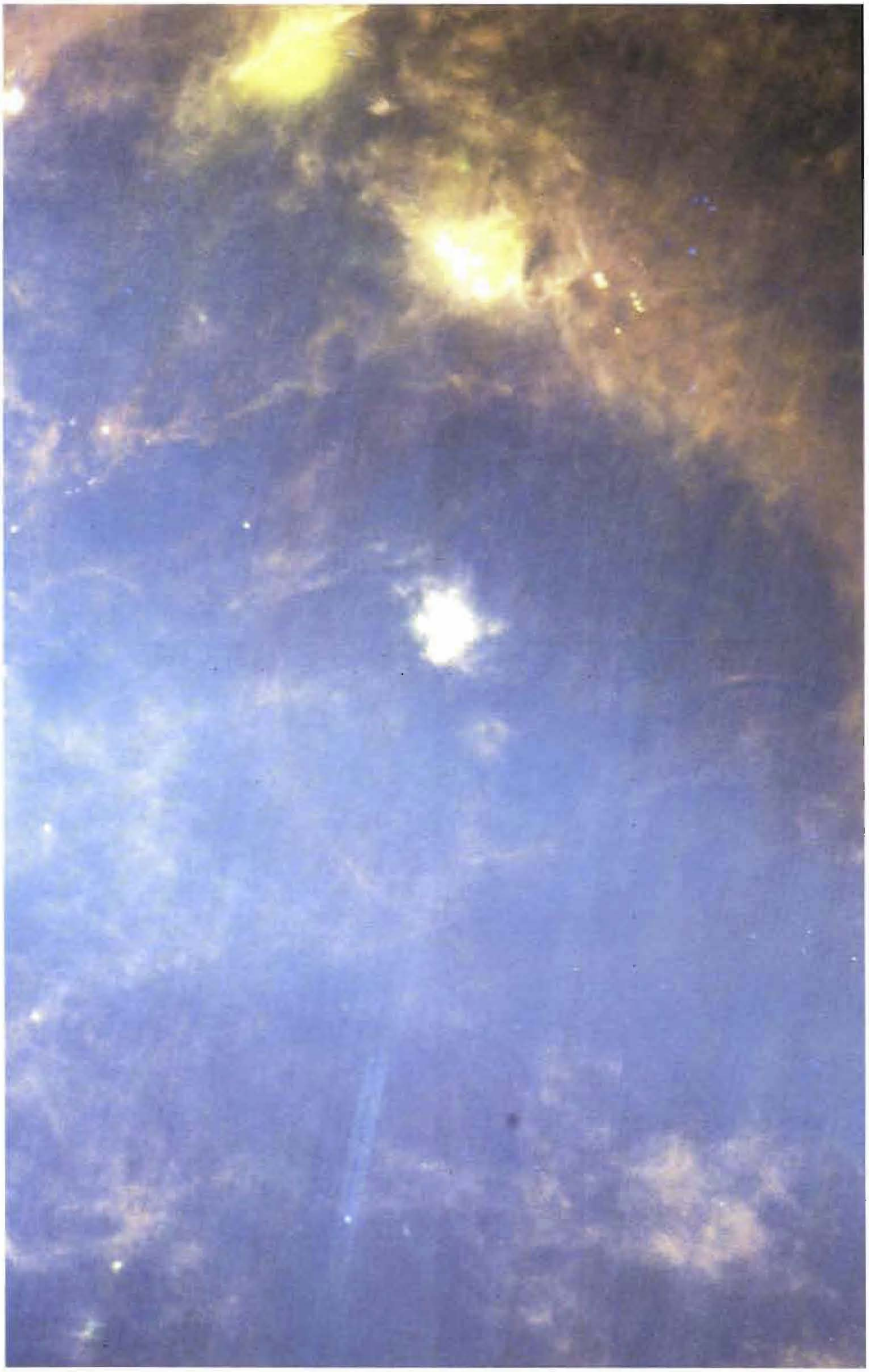


IRAS observations of the entire sky were processed to accentuate different phenomena. The map at the lower left emphasizes extended regions of gas and dust seen in infrared wavelengths throughout the sky. The bright horizontal band is the plane of the Milky Way. The hazy, S-shaped feature that crosses the image is faint heat emitted by dust in the plane of the solar system. Blue represents the warmest material, while cooler material appears red.

The map at the lower right was processed to show the more than 250,000 point sources seen by IRAS. Again, the plane of the Milky Way runs horizontally across the image. Black stripes in both images are regions that were not scanned by IRAS.







Clusters of young stars and many sites of star formation are seen in this IRAS image of the region around the constellations Taurus and Perseus. The warmest material is blue, intermediate temperature material is green, and cool material is red. The white nebula at the center of the image is the Pleiades star cluster. Other, smaller bright knots are associated with the optical reflection nebulae and the small regions of ionized hydrogen that accompany newly forming stars.

International Missions

The DSN continued with its plans to support a number of international missions on a reimbursable basis: MS-T5, Planet A, and BS-2B from Japan; Giotto from the European Space Agency; TV-SAT from West Germany; and TDF-1 from France. The MS-T5, Planet-A, and Giotto missions will study Halley's Comet; the others are synchronous satellites that will be supported by the DSN on the way to their permanent locations.

Technology Development

Antenna Efficiency Improvement

A number of technology developments in structural, mechanical, and microwave engineering accompanied the continuing upgrading of DSN antennas this past year. The goal is to increase the gain by about 1.9 decibels at X-band frequency (8.45 gigahertz) for the three 64-meter DSN antennas; the rehabilitation and upgrading calls for increasing the diameters of the antennas to 70 meters.

A new automatic subreflector for the large antennas, for example, will improve pointing precision and reflector surface alignment at different tracking angles. Tests indicate that the goal of increasing the efficiency from 50 percent (for 64 meters) to 67 percent (for the 70-meter upgraded antennas) can be met.

Antenna Surface Measurement

The accuracy needed in the measurement and adjustment of large radio antennas has reached the limit of conventional survey methods. A new holography technique holds promise for higher levels of precision, by revealing surface deviations as phase fluctuations in illumination across the antenna aperture. In initial use of the JPL technique, the surface accuracy of the 64-meter antenna at the Australian complex was measured with a precision of better than 1 millimeter.

Remote Operations Technology

The DSN's 26-meter antenna at the Goldstone complex has been tracking and commanding the Pioneer 8 spacecraft without human attendance by means of remote control from the Network Operations Control Center at JPL.

Pioneer 8 has completed its primary scientific mission; now, it is being used to demonstrate equipment and procedures for automated stations. The equipment includes a fast Fourier-transform analyzer for the acquisition of signals close to receiver threshold and a set of microprocessors for antenna control and monitoring functions. Using this equipment, a single operator controls the entire station and performs two-way spacecraft tracking from the remote location.

VLSI Correlation Chip

A very-large-scale integrated (VLSI) chip has been designed for the correlating required in very long baseline interferometry, a technique in which combinations of antennas are used in radio navigation, geodynamics, and radio astronomy.

The chip uses two correlators that offer choices of quantization and sampling density. These operations are computationally demanding, requiring up to 768 million multiplications per second. The chip contains about 10,000 gates and 35,000 NMOS transistors, has 48 pins, runs at 16 megahertz, and will use a little more than 1 watt of power.

VLSI Encoder Chip

The encoders and decoders used for error correction in spacecraft and by the DSN are examples of devices that can also benefit from VLSI technology. VLSI offers increasing signaling efficiency by allowing the use of more complex and more flexible coding schemes.

A first demonstration of this concept at JPL was the multicode con-

volutional encoder chip designed in 1983. The chip is capable of encoding any of four convolutional codes; it measures only 2.4 by 1.9 millimeters and will handle a data rate of 1.5 million bits per second.

Space-to-Space Optical Communications

Achieving a high power-utilization efficiency is one of the necessary ingredients for workable space-to-space optical communications systems. JPL researchers have demonstrated that optical signals can be used to transmit information over a free-space channel with a power efficiency of 2.5 bits per detected photon. The demonstration system, built around an 8-bit Reed–Solomon encoder/decoder, actually exceeded the goal: 3 bits per detected photon is obtainable for a bit error probability of approximately 1 in 10,000.

Other key components in space-to-space optical communications systems are high-brightness, single-mode laser emitters. Lasers using gallium–aluminum–arsenide (GaAlAs) semiconductors are preferred mainly for their efficiency and reliability, but their optical power is limited to about 10 milliwatts.

Researchers at JPL have shown, however, that single-spatial-mode devices with power outputs of about 1 watt can be achieved by coherently combining a number of GaAlAs lasers in what amounts to a phased array. The JPL approach yielded peak power outputs of 1.1 watts in low-duty-cycle operations. Applications are expected in both deep-space and intersatellite relays.

Science

Geodynamics

The geodetic measurement program collected regional deformation data at numerous sites in the southwestern United States in 1983, with a significant increase in the number of sites visited. The work was performed with the highly mobile very long baseline interferometry (VLBI) systems based at the Owens Valley Radio Observatory, the DSN Goldstone complex, and Vandenberg Air Force Base.

Twenty-eight sites were visited in 1983, including the Mammoth Lakes region of California, which was added in response to recent seismic activity. Information gathered last year and in periodic revisits will be coordinated with geophysical data from other participating agencies, such as the Caltech Seismological Laboratory and the U.S. Geological Survey, to evaluate tectonic activities in the region.

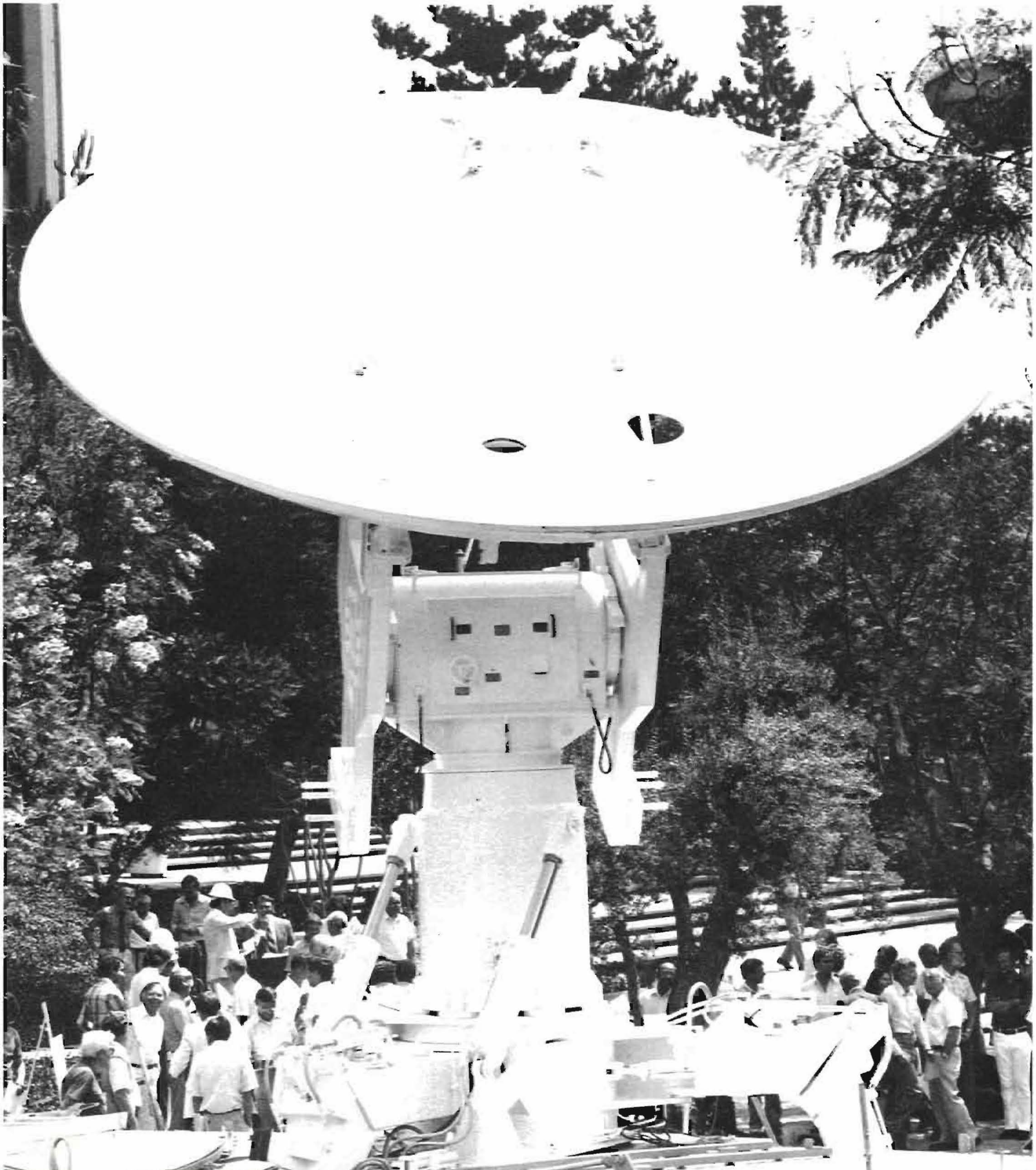
A permanent base station dedicated to VLBI measurements was completed at the Goldstone complex in 1983. It will be used to collect data on regional deformation in Southern California and on intercontinental plate stability when used with the European and Australian stations. The 12.2-meter-diameter antenna has been designated the Mojave Base Station and will also serve as the operations base for the mobile VLBI systems.

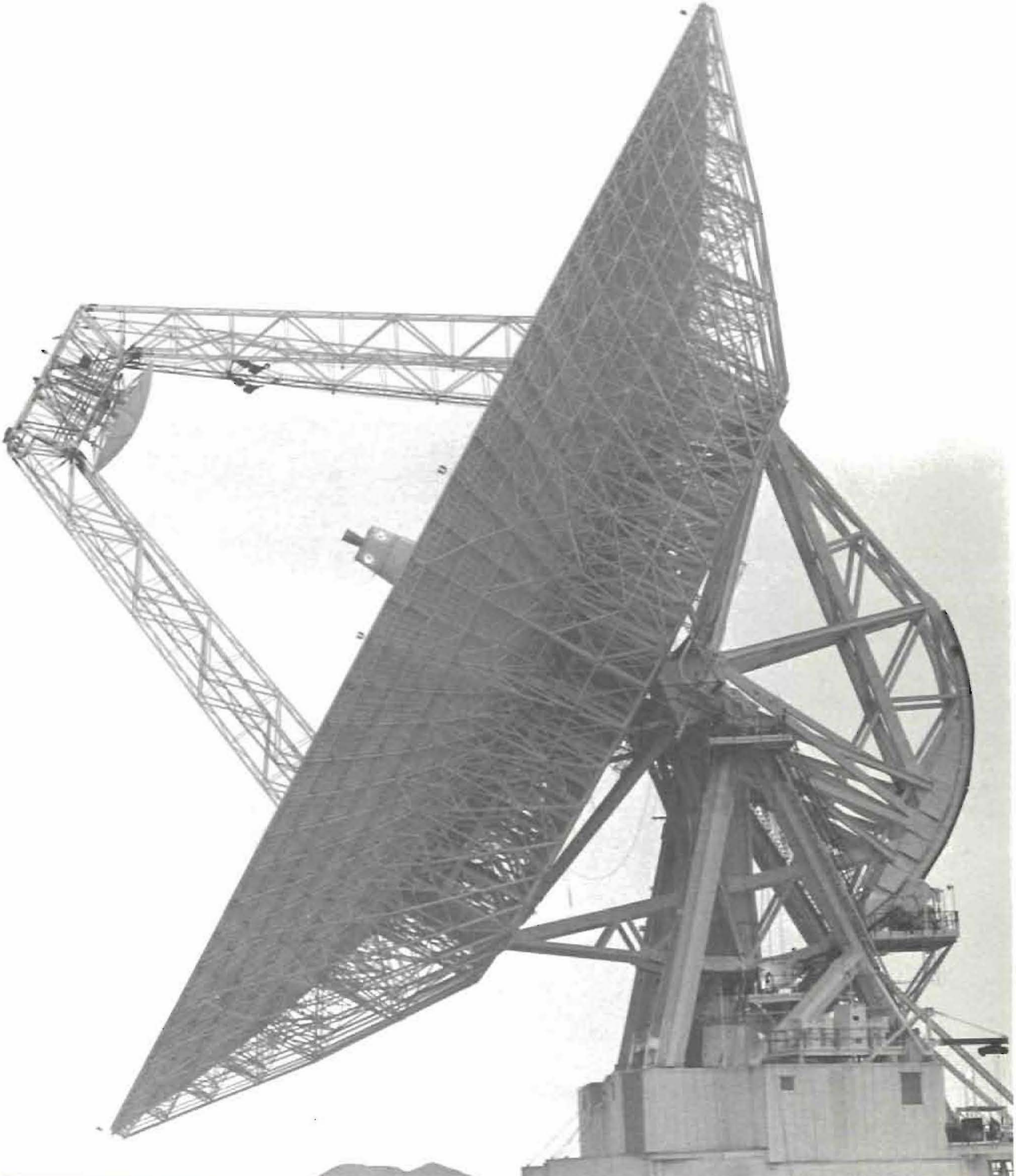
Lunar Laser Ranging

The Lunar Laser Ranging (LLR) program made substantial improvements this past year in the mathematical modeling of the Earth–moon system. Analysis continued of ranging data determined by the transmission of laser pulses from McDonald Observatory in Texas to retroreflectors placed on the moon's surface during the Apollo program.

The ability to model the lunar orbit over the full 13-year observational span permits studies of relatively long-term variations in Earth's rotation, as well as highly accurate determinations of Earth–moon dynamics. LLR data have also been applied to studies of changes in Earth's oblateness (the flattening at the poles) and the role of atmospheric changes in fluctuations of Earth's rotation and angular momentum.

JPL's Geodynamics Program developed this mobile, 5-meter-diameter antenna, which will be used to collect data related to the movements of Earth's crustal plates.





The giant 64-meter antenna at Goldstone is seen before extensive rehabilitation began to alter its appearance—and improve its capabilities for the next two Voyager encounters.

Radar Detection of Comets

Comet IRAS-Araki-Alcock approached close enough to Earth in May 1983 that DSN radar astronomy techniques could be used to study the details of its nucleus. In optical observatories, the glow of ionized gases and scattered light from dust particles would completely obscure the details of the nucleus, even if it could be resolved by Earth-based optical telescopes. Radar provides new ways to achieve resolution based on precise measurements of the energy in the Doppler-shifted spectra.

A 64,000-line spectrum analyzer was used for the measurements, which were carried out by transmitting a 400-kilowatt continuous-wave monochromatic signal to the comet. The data can be interpreted in terms of the comet's rotation, size, and surface properties. One theory is that the nucleus may rotate less than once a day, be a few kilometers in radius, and have a somewhat dull reflecting surface. Another theory argues that the comet may rotate more rapidly, have a small radius, and have a super-reflecting surface.

Milliarcsecond Radio Astrometry

Development of a catalog of about 100 extragalactic radio sources, giving source positions with an accuracy of approximately 0.005 arcseconds, is one goal of the DSN's radio reference-frame program. Such an accurate catalog is required to provide a framework for the navigation of spacecraft to the planets.

Accuracy goals are currently set by the navigation requirements of the Galileo probe entry into the atmosphere of Jupiter. These navigation requirements have become sufficiently stringent that the reference stability and accuracy offered up to now by the stars in our own galaxy are no longer adequate. A distance of billions of light-years—the distance to the quasars—is needed to obtain the necessary reference frame.

The positions of some 120 radio sources have been estimated by means of very long baseline interferometry (VLBI) observations using the DSN antennas on two intercontinental baselines: California–Spain and California–Australia.

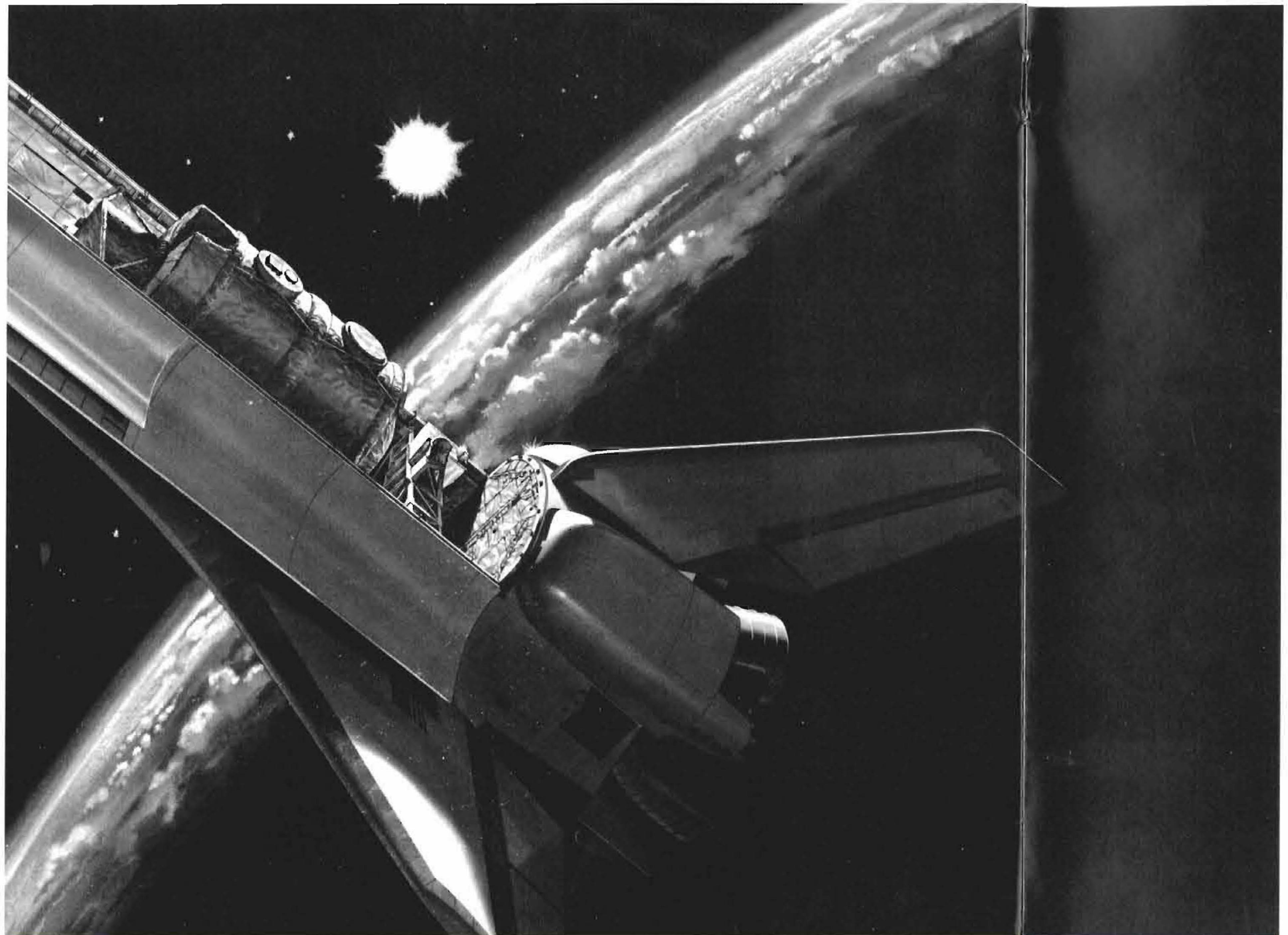
The formal uncertainties of these radio-source positions are 2 to 10 milliarcseconds (mas). Comparison with measurements of a smaller part of the sky showed a root-mean-square difference of 4 mas in right ascension and 7 mas in declination. In more concrete terms, an ellipse of this angular size at the distance of Jupiter would have axes of only 15 and 24 kilometers.

Computing and Information Services

The Computing and Information Services System project was initiated in 1983 with the primary objective of developing and adopting modern computing, networking, and information services technology to meet JPL's future data-processing and data-management requirements.

There are two major parts to the five-year project. The first is the Technical and Administrative Computer Communications Network, which will provide institutional computing capability and communications between computers, users, and data bases. The second part, the Management and Administrative Support System, will provide a centralized interactive data base containing the information and systems needed to manage JPL and its projects.

Earth Observations



JPL's Earth-observation programs are dedicated to improving contemporary understanding of the chemical, physical, biological, and geological processes occurring in and above the atmosphere, in the oceans, on the landmasses, and in the planet's interior.

As it does in most endeavors, JPL takes a "systems" approach to its study of Earth. In this view, Earth is one giant system of parts—the atmosphere, the land, the oceans, the polar ice—that interact on time scales ranging from hours and weeks to hundreds of years.

To understand these "subsystems" individually, researchers need to understand them in the larger, global sense as well; to understand the subsystems thoroughly, scientists need to measure many parameters simultaneously. For these reasons, they have turned to orbiting platforms such as satellites and space shuttles. And since the different effects are more readily measurable in specific bands of the electromagnetic spectrum—microwave, infrared, ultraviolet, and so forth—scientists are developing a variety of sensors.

A good example of subsystem interaction is the phenomenon of El Niño and the southern oscillation, an oceanic and atmospheric disturbance that occurs every few years.

El Niño is usually preceded by strong equatorial trade winds piling up water against the coasts of Southeast Asia. A typical El Niño/southern oscillation begins when the atmospheric pressure over the western Pacific starts to rise, the trade winds slacken and sometimes even change direction, and the piled-up water starts moving back, picking up solar heat on its way to South America. The result can be disastrous extremes of weather on both sides of the Pacific.

Scientists are studying the multiple causes and effects of El Niño—and why the 1982 cycle, the most severe this century, did not begin with the usual buildup of the trade winds. But they need better data on surface temperatures, wind speeds and directions, and ocean elevations. They need, in effect, more than one independent "witness," more than one type of sensor to carry out their work.

Two such sensors are being developed at JPL: the Ocean Topography Satellite, which will carry an altimeter to measure sea-surface heights; and a scatterometer, to be carried on a U.S. Navy satellite, that will measure near-surface oceanic winds. These and other instruments will help explain the complex air–sea interaction of which El Niño is a part.

JPL is employing this same systems approach with other questions, such as that of the stratospheric ozone layer's stability. Besides instrument development, this work includes data analysis, laboratory research, and theoretical studies—all aimed at a better understanding of Earth.

Free-Flying Missions

JPL is conducting work in support of a number of free flyers, such as Earth-orbiting satellites and NASA's proposed Space Station.

Much of the JPL effort is directed toward another new NASA proposal, a multidisciplinary investigation of Earth's biosphere during the 1990s and beyond. The program would lead to the collection of several 10-year data sets on Earth's vegetation, winds, oceans, polar ice, and continental geophysics and geochemistry.

In addition to continuing work in developing synthetic-aperture radars and other sensors, JPL is studying various spacecraft options in support of the proposal. One would use hardware developed in common with the Space Station; another would employ existing commercial spacecraft. Planners are also studying a specially designed unmanned orbital spacecraft as a third option.

Operating from a shuttle, ATMOS will study the upper atmosphere by measuring the sunlight passing through it.

A space shuttle prepares to dock with NASA's Space Station, which may take the form suggested by this artist's concept.

TOPEX

The Ocean Topography Satellite (TOPEX) would be launched in the late 1980s on a mission to map the circulation of the world's oceans, using detailed altimetric measurements of the sea surface.

TOPEX's altimeter would measure ocean-surface height variations with an uncertainty of only 14 centimeters. From such measurements, scientists could determine details of currents, eddies, and other features of ocean circulation. Detailed analysis, in addition, would reveal aspects of the geologic structure of the seafloor.

Information gathered over three to five years would be used to determine the global ocean's average behavior and to calculate small-scale changes and fluctuations in the ocean's circulation. This information is critical to understanding general trends—the role of the oceans in the takeup of carbon dioxide from the atmosphere and in the formation of weather and climate—as well as specific phenomena like El Niño.

In 1983, JPL entered into a collaborative mission study with Centre National d'Etudes Spatiales, the French space agency, which also intends to perform an ocean experiment. The joint study will determine if a combined mission—called TOPEX/Poseidon—would be feasible and could meet both organizations' objectives.

Three aerospace firms are working on contracts to conduct satellite-definition studies for TOPEX. Each of the companies—Fairchild Industries, RCA Corporation, and Rockwell International—will propose an Earth-orbiting satellite to be modified for use as the TOPEX spacecraft. They will study configurations for the U.S.-only option, which will be designed for launch from a space shuttle, and for the U.S.-French configuration, designed for launch from a French Ariane 4 vehicle.

Microwave Limb Sounder

The Microwave Limb Sounder is one of 11 instruments being developed for flight on the Upper Atmosphere Research Satellite in 1989. Data from the satellite will test and extend our present understanding of Earth's upper atmospheric chemistry.

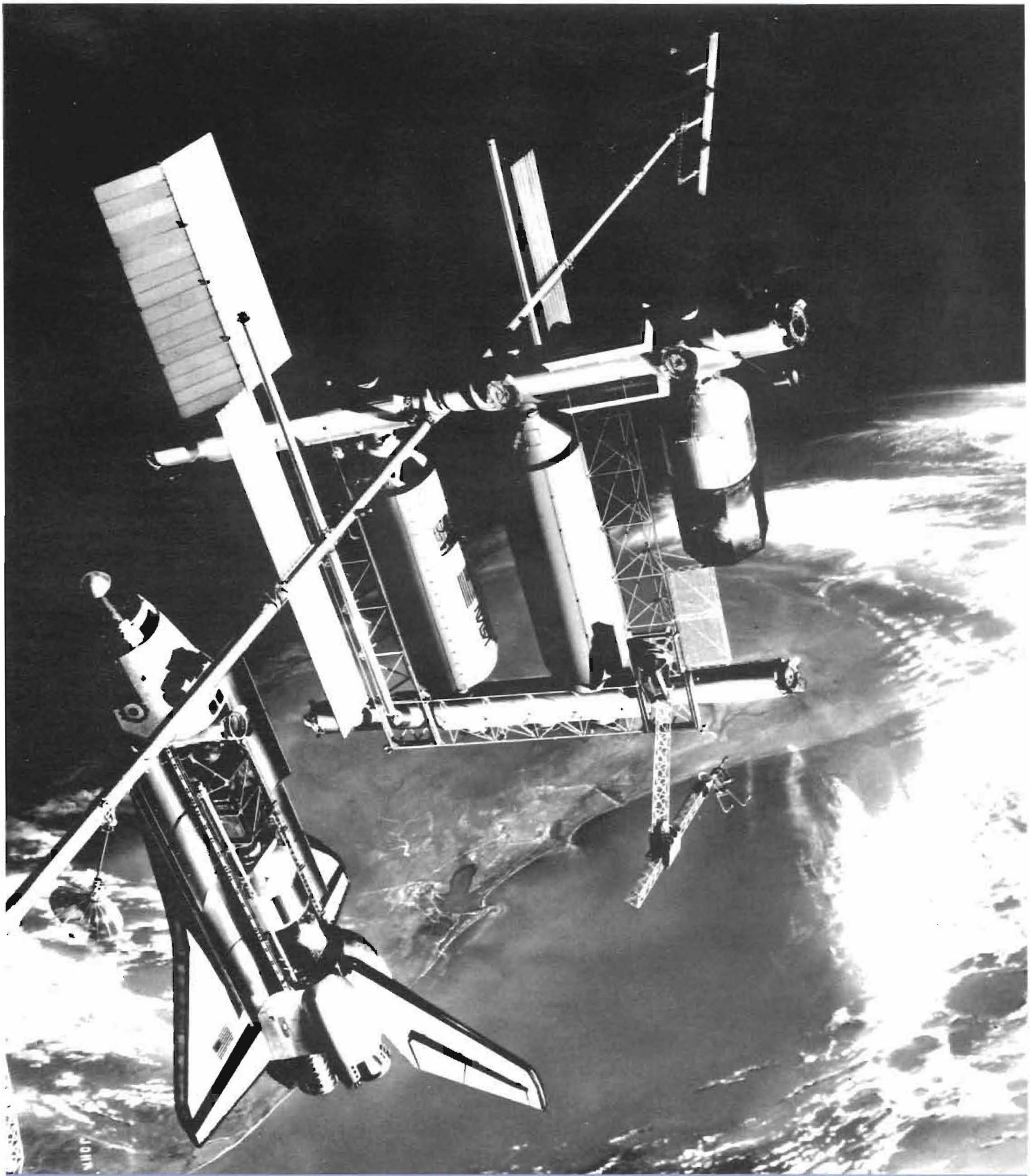
The JPL instrument will obtain vertical profiles of chlorine monoxide, ozone, and hydrogen peroxide day and night for a minimum of a year and a half. It will measure millimeter-wavelength thermal emissions in selected bands corresponding to the chemicals of interest, and take accompanying pressure measurements.

A vibrational test model and a protoflight model will be built inhouse, with the antenna reflectors, power supplies, and actuators procured from industry. Breadboards of key elements have been built and are being tested.

Space Station

In January 1984, the White House announced a new initiative to orbit a Space Station in the next decade. As currently defined, the initiative includes a manned station in low-Earth, near-equatorial orbit plus platforms associated with the manned station either by proximity or commonality of technology.

JPL supported NASA's Space Station studies in four major areas in 1983: customer interaction and use; end-to-end information systems; autonomy and automation; and Earth-resource platforms. In the autonomy and automation area, for example, JPL led the development of a rationale and requirements. The conclusion was that a mixture of human- and machine-performed functions would be best, with routine and dangerous functions being increasingly handled by machines as the Space Station evolves.



Space Shuttle Experiments

Work is progressing toward the flights in 1984 and 1985 of a series of space shuttle experiments from JPL, as Laboratory researchers continue to apply the new space-science capabilities afforded by the shuttles. The JPL experiments are designed for repeated flights, in order to take advantage of the increasing frequency of shuttle missions and thus collect data over cycles of many years.

ACES

The Acoustic Containerless Experiment System (ACES) is a reflyable space shuttle mid-deck payload designed to demonstrate for the first time the use of three-axis acoustic levitation for "containerless" processing of materials at high temperatures in the microgravity environment.

During its initial flight in February 1984, ACES melted, manipulated, and then resolidified a sample of fluoride glass, a material that may one day be used in low-loss optical systems. Video recordings of the process are being analyzed.

Shuttle Imaging Radar

The Shuttle Imaging Radar-B (SIR-B) will be flown in fall 1984 as a more sophisticated follow-on to the SIR-A instrument that flew aboard the second shuttle mission three years ago.

SIR-B, a synthetic-aperture radar, will use an upgraded version of the basic hardware of its predecessor. Improvements include a wider bandwidth, which will allow imaging resolution of 16 meters; a completely digital data-handling system; capability for a variable illumination geometry with a controllable antenna; and a high-accuracy calibrator.

Synthetic-aperture radar enables observers to make photograph-like images of target surfaces and to peer through clouds, darkness, and even thin covers of sand and alluvium in arid regions.

From its vantage point in the shuttle payload bay, SIR-B will conduct subsurface mapping in North Africa and will help study African rift-valley geology, tectonics in eastern Turkey and the southern Andes, vegetation in the central United States and Western Europe, and ocean waves off the U.S. east coast and the southeastern coast of Africa. These are some of nearly 50 scientific investigations to be carried out by researchers from many countries.

ATMOS

The Atmospheric Trace Molecule Spectroscopy (ATMOS) experiment has completed all JPL preflight testing and is undergoing integration into the Spacelab 3 payload for launch in January 1985. Solar testing on the ground has already provided valuable data on properties of the atmosphere.

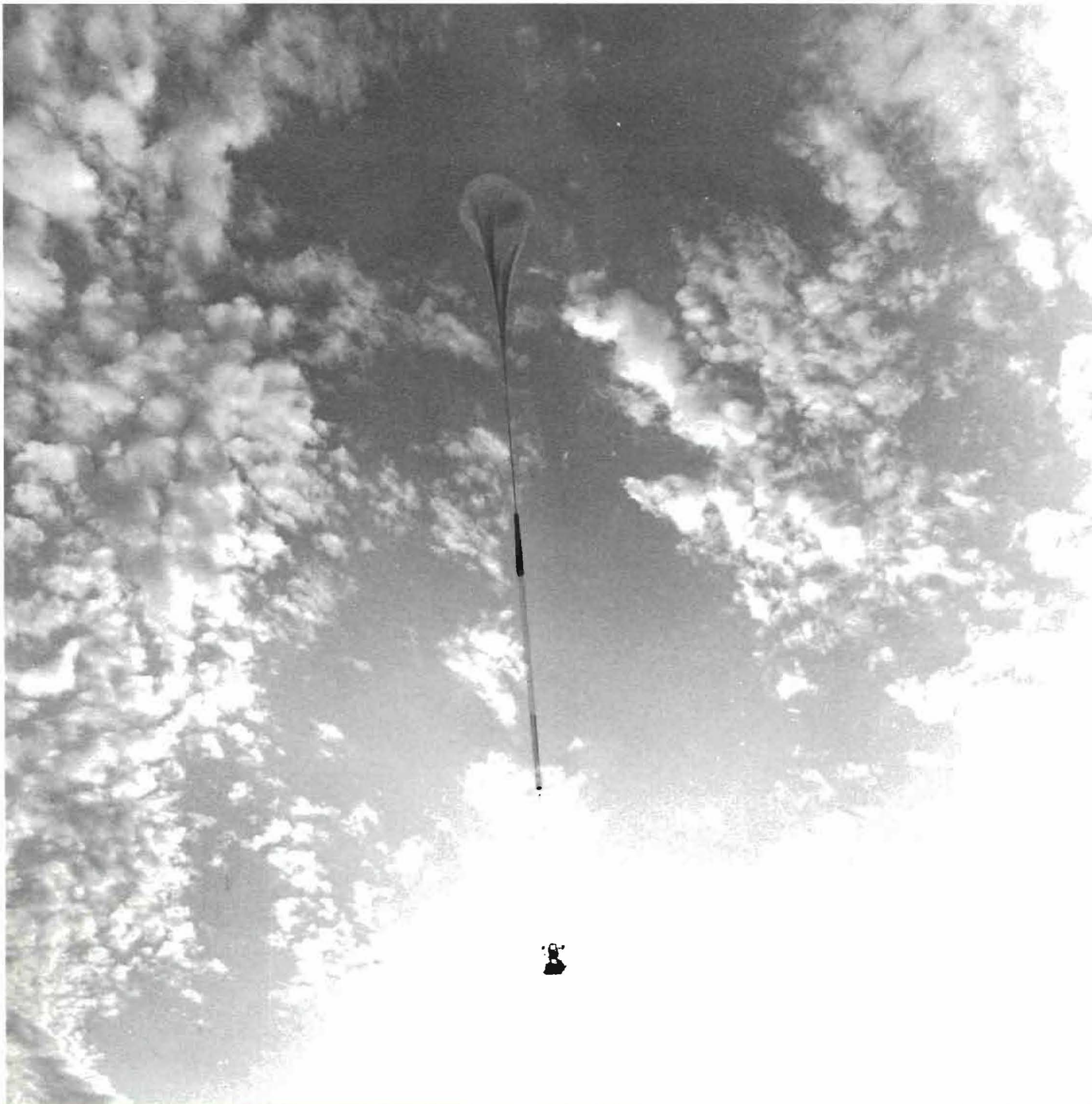
ATMOS is a reflyable instrument designed to obtain fundamental information on the chemistry and physics of the upper atmosphere. It is a high-resolution, interferometric spectrometer that will measure the atmospheric absorption of sunlight and from the measurements determine the types and quantities of molecules at altitudes of 15–120 kilometers.

Drop Dynamics Module

The Drop Dynamics Module (DDM) will join ATMOS as part of Spacelab 3 in early 1985. The experiment will use acoustic levitation to position liquid drops in the absence of gravity; DDM data on the behavior of the rotating and oscillating samples may contribute to fluid-dynamics theory and help guide future attempts to manufacture materials in space.

Two JPL scientists—Dr. Taylor Wang and Dr. Eugene Trinh—are being trained as payload specialists to fly with DDM and perform experiments on Spacelab 3. It is anticipated that DDM will be reflown 10 times during the next decade, conducting increasingly complicated studies of liquids, bubbles, and nonperiodic dynamics.

Dressed in a clean suit, an engineer helps attach the Shuttle Imaging Radar-B (SIR-B) to a pallet at the Kennedy Space Center in Florida. The pallet, carrying a host of radar experiments, is expected to fly on a space shuttle in fall 1984.



Superfluid Helium Experiment

The Superfluid Helium Experiment will investigate the mechanical and thermal properties of superfluid helium, a liquid that offers high performance and reliability in cryogenic cooling systems. At year's end, the experiment was undergoing final JPL testing in anticipation of installation in Spacelab 2 for a shuttle flight in April 1985.

The experiment will measure the motions of the liquid during small accelerations of the shuttle and will measure the resulting minute temperature changes. It will also study the propagation of waves that cannot be observed in laboratories on Earth because of the presence of gravity. This set of data will add to the knowledge of superfluid helium's properties that JPL acquired while developing the Infrared Astronomical Satellite.

Science

Atmospheric Science

Balloon Intercomparison Campaign. The second phase of the Balloon Intercomparison Campaign was conducted in June to gather data on the composition of the stratospheric ozone layer. JPL played a key role by contributing scientific instruments, two of four balloon gondolas, instrument flight support, and coordination at the launch site in Texas.

All four flights were carried to completion. The resulting data set will allow researchers to intercompare results from the different types of instruments and to compare the findings with atmospheric models. The campaign was marred by the loss of one of the JPL gondolas, which free-fell to the ground from 107,000 feet. The gondola is being replaced.

Geology

Imaging Spectrometer. Continuing development of the next generation of land remote sensors has produced the first significant rock- and mineral-identification results. JPL scientists fitted their Airborne Imaging Spectrometer (AIS) with a new charge-coupled-device detector, giving the spectrometer the ability to acquire data simultaneously in 128 adjacent, narrow spectral bands. The large number of bands imaged allowed direct identification of many kinds of surface minerals, as confirmed by laboratory analysis of collected samples.

The AIS is being tested over a number of sites for its ability to identify forest and range-land species, determine plant stress, and map mineral deposits. A larger airborne device is under construction, and a free-flying instrument, the Shuttle Imaging Spectrometer Experiment, has been proposed for flight in 1989.

Oceanography

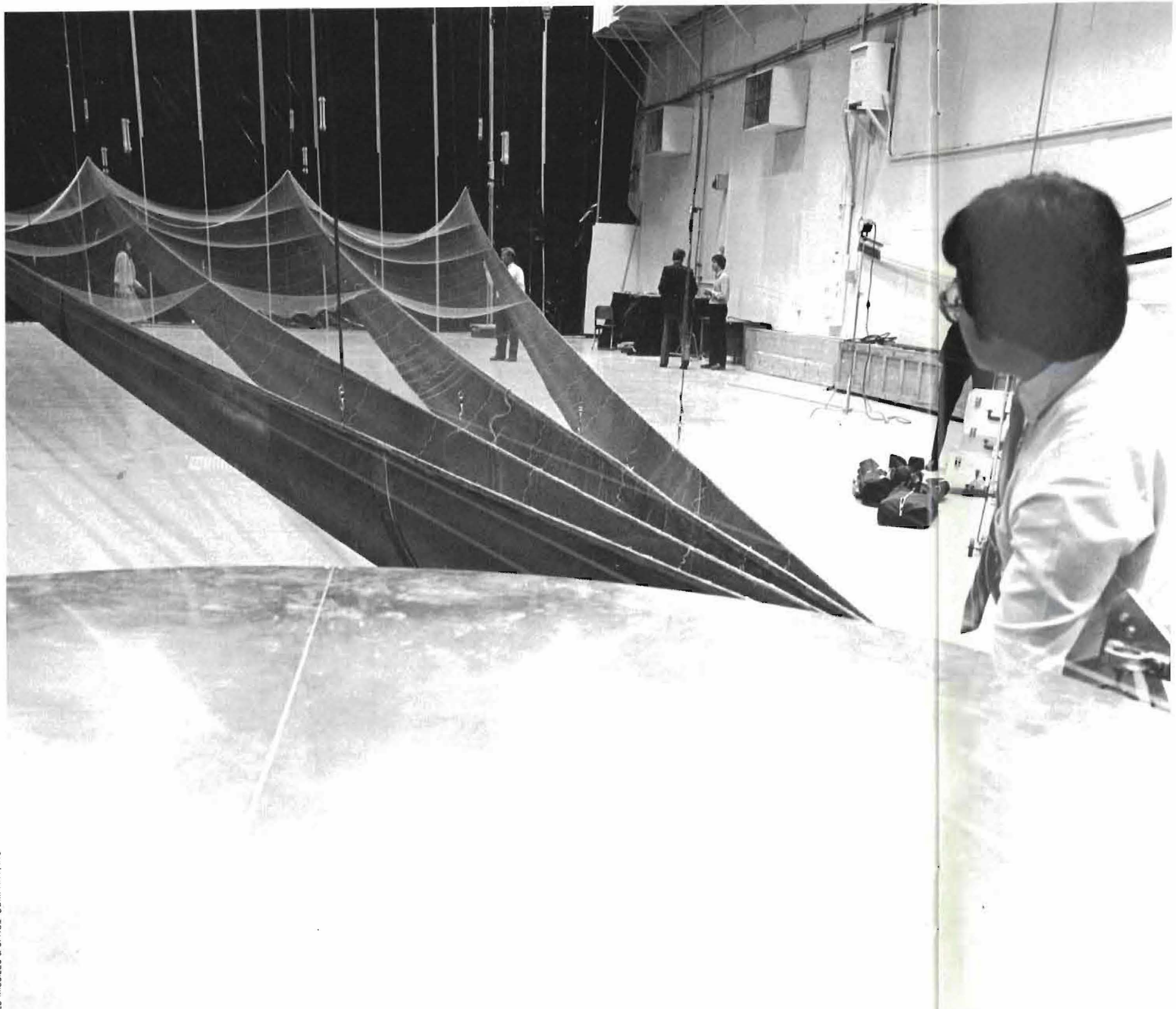
Biota and Ozone Destruction. JPL researchers are working to determine the significance of naturally occurring chlorine in the destruction of ozone in Earth's stratosphere. Their calculations indicate that much of the compound methyl chloride, which accounts for 30 percent of the total chlorine budget, comes from the decomposition of kelp and other brown algae by microbes. This finding suggests that these biota are an important oceanic source of methyl chloride and thus chlorine, which is responsible for 15 percent of ozone destruction.

Pilot Ocean Data System. The advent of remote-sensing satellites calls for new techniques for managing an unprecedented volume of information. The Pilot Ocean Data System (PODS) is the first major attempt to provide scientists with effective access to oceanographic-satellite data sets.

In 1983, PODS improved on the existing system and began investigating new data-management technology, such as digital optical devices for mass storage. PODS continues to support its on-line data archive and delivery system, which gives investigators around the world immediate telephone-link access to Seasat and other data sets.

An instrument-laden science payload descends to Earth after a successful data-gathering flight during the 1983 Balloon Intercomparison Campaign.

Advanced Technology



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NASA's plans for solar system exploration during the remainder of the 20th century will require the continuing development of advanced technology to fully exploit the potential of future missions. JPL's goal is to support NASA in the utilization of advanced technology and to promote the speedy exploitation of fundamental discoveries for the nation's space-exploration program.

This past year, JPL has worked to bring leadership and focus to its technology-development efforts. First, Dr. Terry Cole has been appointed to the reestablished position of chief technologist. He will hold responsibility for advocating, reviewing, and planning technology activities in the Technical Divisions.

In addition, a JPL Technology Board has been created, with membership consisting of leading technologists from the Laboratory and the Caltech faculty. The board will support the assistant laboratory director for the Technical Divisions in assessing technology needs and determining priorities.

Examples of the Laboratory's efforts to provide coordination and direction to its diverse technology efforts are the new initiatives being developed in advanced microelectronics and in optical systems.

Advanced Microelectronics Program

Program Structure

The mission of the Advanced Microelectronics Program (AMP) is to conduct long-range research and development in this growing field. AMP is designed to support JPL's NASA and Department of Defense (DOD) missions and to make the Laboratory a center of excellence in selected areas of advanced microelectronics.

The program is structured to emphasize those aspects of computational and device electronics that are characteristic of JPL's responsibilities to NASA and DOD. A strong and synergistic collaboration with advanced research projects on the Caltech campus will form an integral part of the program.

AMP will investigate new and existing scientific concepts necessary for the development of electronic devices, materials, and sensors in support of NASA objectives. It will discover, develop, and evaluate new electronics concepts for improved sensor compatibility, high-rate information transfer and storage, ultra-high-reliability components, and real-time signal processing.

More than 20 new research initiatives have been started in the four AMP technology areas: computer architecture and subsystems, advanced solid-state device technology, optoelectronics, and spaceborne very-large-scale integration (VLSI). Seed monies have been provided by NASA and DOD, the JPL Director's Discretionary Fund, and the Caltech President's Fund.

Computer Architecture and the "Hypercube"

A specific example of the type of technology development taking place under AMP is the subprogram for computer architecture and subsystems.

The past 30 years have seen the rapid development and utilization of the sequential computer—central processor unit, memory, and input/output devices—to perform time-ordered sequences of operations on stored data.

But without further breakthroughs, the power of sequential computers will be limited to about 10 times the fastest present computers, because of fundamental limitations on device-packing density and the speed at which signals can be sent from one part of the computer to another. Many areas of space exploration and aeronautics will need computing power 1,000 times greater than is now available.

The answer to this need is a new computer architecture in which infor-

Engineers inspect a prototype of the world's largest space antenna, which JPL is developing for NASA. The ultimate structure could span 100 meters.

An engineer tests one configuration for an underwater ocean instrument capable of the remote measurement of sea-water temperatures and salinity. The laser-based instrument is being developed as part of JPL's Optical Systems Research Initiative.

mation is processed in parallel, or concurrently, in an array of central processing units. Many approaches to concurrent processing have been proposed, but only a few have been explored experimentally.

One of the most promising of these is the so-called "hypercube" machine being developed by Caltech Professors Geoffrey Fox and Charles Seitz. AMP researchers from JPL are collaborating in developing the device and associated specialized software.

In the hypercube architecture, 2^n processors are connected in an array such that each processor communicates its results to n neighboring processors. (In the case of $n = 3$, for example, the array would contain eight processors, each of which can communicate with three neighbors.) Each processor in the array is symmetrically equivalent, and each has its own memory. Computation proceeds independently and asynchronously in parallel in all processors at the same time.

The power of the hypercube grows proportionally to the number of processors in the array. Because of the regularity of its design, the hypercube can be scaled up to very large machines with relative ease; its cost can be kept low because it uses relatively inexpensive, commercially available computer chips for each processor.

The hypercube's designers predict that the ultimate machine will have as many as 30,000 processors with a computing power more than 1,000 times greater than today's fastest supercomputers. The campus group, in collaboration with JPL engineers and scientists, has built a 64-processor hypercube that achieves six times the power of a Digital Equipment Corporation VAX 11/780 computer at one-tenth the cost of a single VAX.

One of AMP's goals is to sponsor collaboration between JPL and the campus hypercube research group in designing, building, and qualifying a machine containing 1,024 processors that will have a computing capability 50 times that of a Cray-1, today's fastest commercially available sequential computer.

AMP will also develop specialized software for the hypercube solution of computationally demanding space problems such as synthetic-aperture radar data processing, image analysis, modeling of planetary atmospheres, VLSI testing, and design of expert systems for spacecraft operations.

Optical Systems Research

JPL's Optical Systems Research Initiative is being developed in response to NASA's need for new optical systems to take full advantage of the observational opportunities presented by space exploration.

Spaceborne optics must operate outside the atmosphere, where the wavelength coverage, pointing requirements, scattered-light effects, turbulence effects, contamination problems, radiation levels, and thermal environment are entirely different than on Earth.

Because of the unique optical requirements that result, the products of industry for the consumer market will not normally meet NASA's needs in space applications. Future missions will require more diverse and complicated optical systems than have ever before been attempted. A coordinated generic technology program in space optics is required to meet these needs.

A NASA working group has defined such a program for long-range research in optics technology. The plan covers the areas of optical system design and analysis, optical materials, optical fabrication, optical test and alignment, mirror technology, optical subsystem development, and adaptive optics. JPL and other NASA centers will participate in the program.


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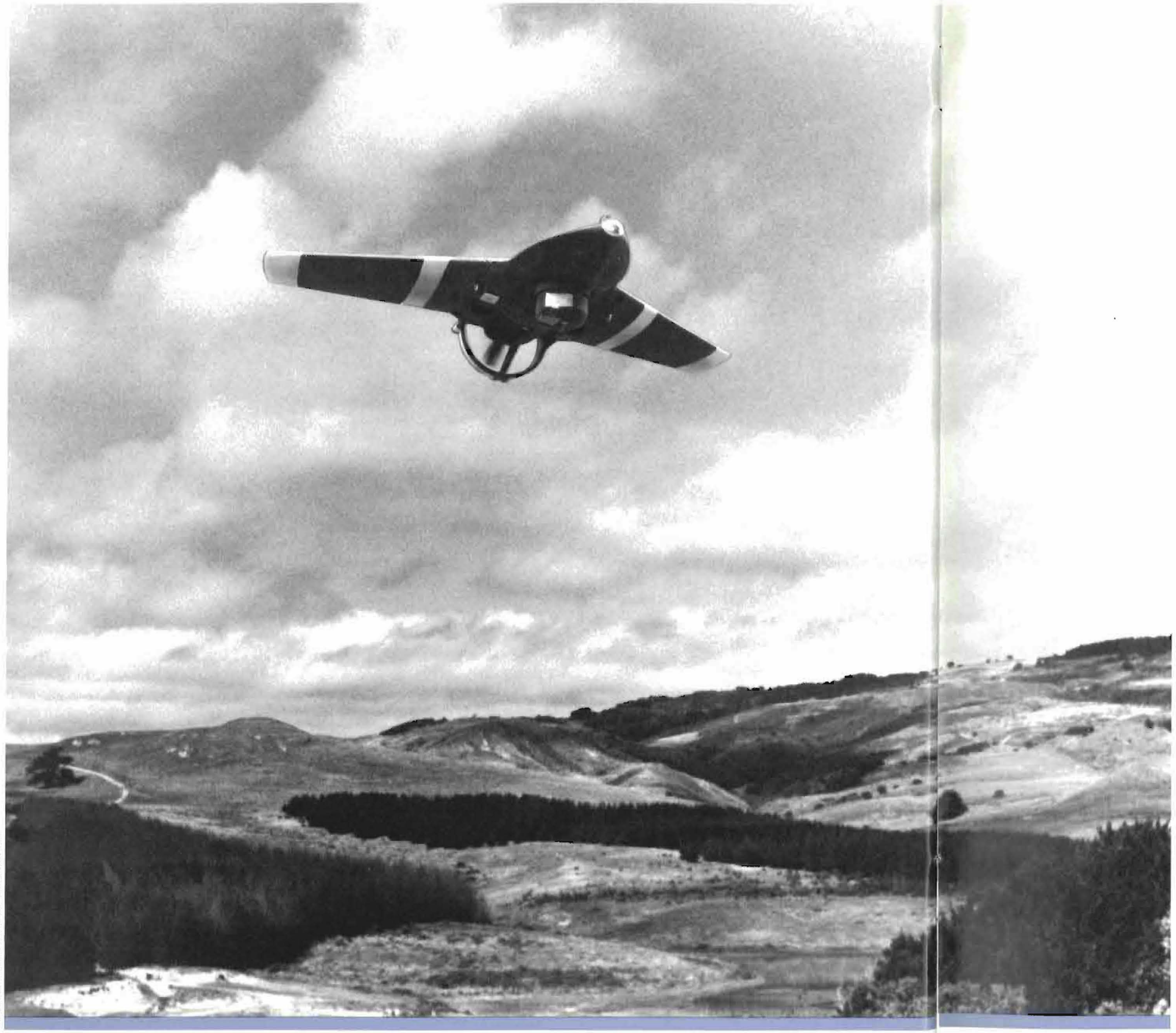

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Part of JPL's distinctive institutional character is its experience in conducting the full range of mission activities, from mission conception through analysis of the returned information. This experience, in the words of Director Lew Allen, "enables effective management of projects with unforgiving deadlines, limited budgets, and high demands for performance."

It is just such a formula for difficulty that characterizes projects for the Department of Defense. With this in mind, JPL has begun to undertake defense tasks—within a ceiling of 20 percent of the Laboratory's total work—as a means of strengthening its unique capabilities while enhancing national security.

Since its formation in 1981, the Defense Programs Office has actively pursued work with the U.S. Air Force, Army, Navy, and Defense Advanced Research Projects Agency. The goal is to seek projects that will complement JPL's more traditional NASA responsibilities and, at the same time, add to the vitality of the institution.

Army Activities

JPL continued work on a number of tasks for the Army in 1983. Among the highlights are

- ☆ The Airland Battle Advanced Technology project, under which JPL is helping to evaluate new technology developments for the Army in four key areas that have been given priority for applications in the early 21st century. The areas comprise very intelligent surveillance and target-acquisition systems; distributed command, control, communications, and intelligence; the soldier-machine interface, with specific applications in robotics and artificial intelligence; and autonomous systems. Results will be incorporated as prototypes in operational demonstrations starting in 1986–87.
- ☆ The Airborne Surveillance Sensor Evaluation Test Bed task, the objective of which is to design, fabricate, test, and deliver an evaluation system based on a complement of passive electro-optical sensors. This system will be used by the Army to evaluate concepts for advanced surveillance technology. The system contains visual, infrared, and millimeter-wave sensors that will be installed as a package on a manned Army experimental aircraft. The sensors will provide surveillance capability day and night and in otherwise obscuring weather conditions. The system also includes a ground relay station and a ground control and analysis station.
- ☆ The Remotely Piloted Vehicle (RPV) project, under which the Army is developing a remotely controlled surveillance aircraft called the Aquila, with management and technical support from JPL. The Laboratory is also working on a frequency-hopping communications system for possible future use in RPVs.
- ☆ The Advanced Material Technology project, which is aimed at developing and evaluating advanced materials and fabrication techniques for lightweight, armored combat vehicles. To date, a variety of test samples have been subjected to impact with promising results.
- ☆ A JPL-developed system that is being used by the Army as a computer-aided means of software management for deployed tactical intelligence systems. It allows analysts to specify changes in software and analyze the resulting impacts. A key to the system is a user-machine interface design that allows the analysts to derive information with maximum effectiveness through the use of advanced computer technology and software.

The Aquila Remotely Piloted Vehicle cruises during a test flight. . .

. . .before being retrieved in a portable recovery net.

Arroyo Center

The Arroyo Center, formerly the Army Analysis program, completed its first full year of operation in 1983. Its mission is to function as a technology and policy study center for the U.S. Army, with the emphasis on long-term, high-priority issues.

Current studies fall in the broad categories of national security, force deployment, supporting services, and military technology. Specific topics include reducing the cost and increasing the efficiency of Army personnel, hardware, and supply, and employing better and less costly technologies for space- and land-based communications, intelligence, navigation, and weather forecasting.

The center, which gained its first full-time director in September, will separate from JPL once the initial establishment and buildup have been completed. Caltech and JPL are committed to supporting the center through its transition to independent status over the next two to three years.

ASAS/ENSCE

Development continued on the All Source Analysis System/Enemy Situation Correlation Element (ASAS/ENSCE) project. Its mission is to provide the capability for intelligence data processing, which would be used by commanders making decisions in the field. Joint sponsors are the Army and the Air Force.

This tactical intelligence system, which will employ computer workstations housed in protected field shelters, will be capable of automated message processing. It will also include equipment that will provide data to analysts who will integrate information going to battlefield users. ASAS/ENSCE will employ commercial hardware to a great extent, including ruggedized versions of Digital Equipment Corporation's VAX 11/730 and 11/750 computers.

Completion of the definition phase is expected in 1984, with a baseline system intended for operation in the late 1980s, and the final system in the '90s.

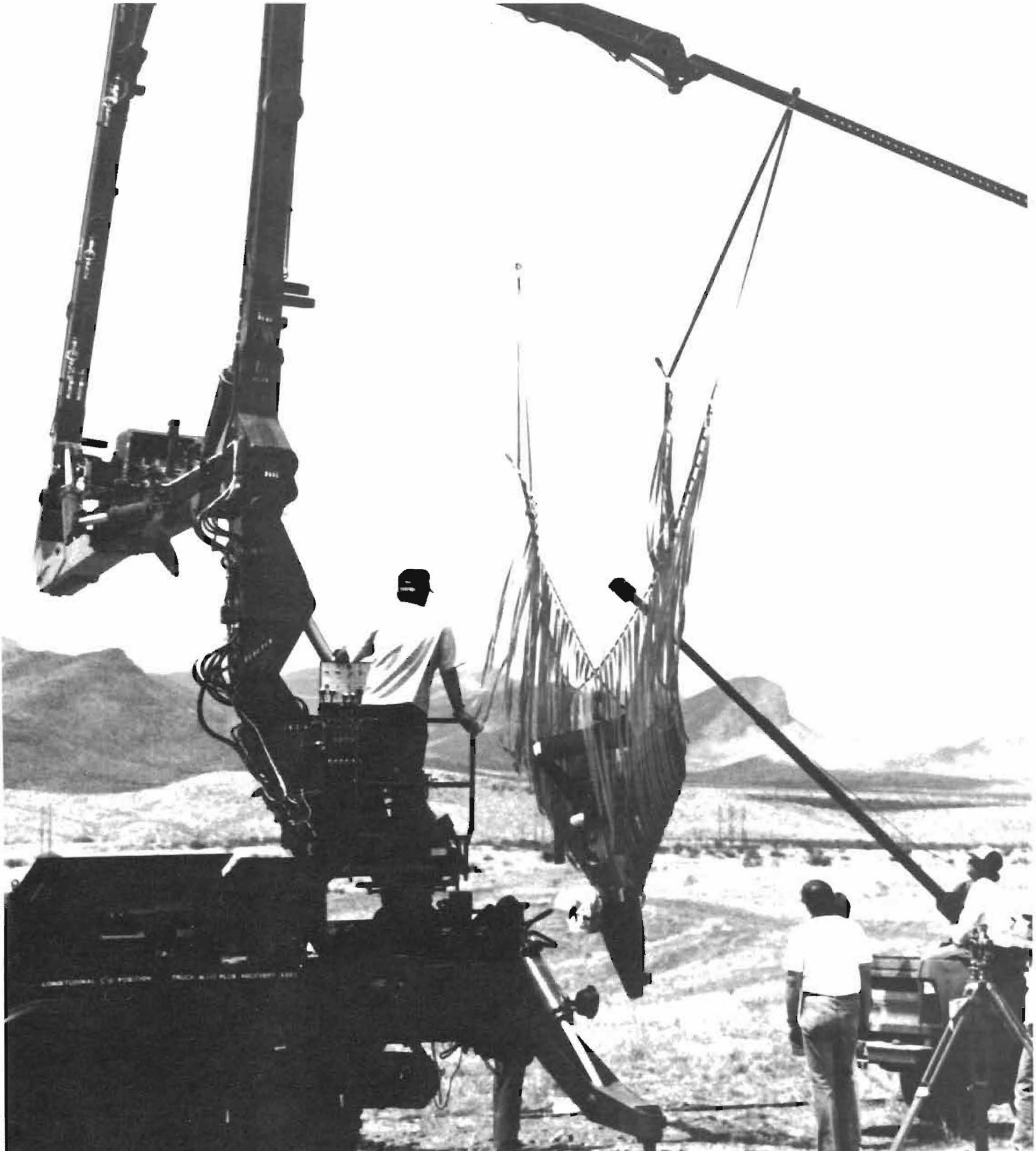
Autonomous Spacecraft

Work continued on the Autonomous Spacecraft project for the Air Force Space Technology Center. The goal is to achieve, by the end of the decade, a high degree of autonomy and independence from ground stations for defense satellites. The project draws heavily on JPL's experience in developing planetary spacecraft that must function at great distances from Earth-based control centers.

Design, development, and demonstration are under way for a prototype fault-tolerant, computer-based spacecraft subsystem for defense satellites. An autonomy demonstration of the prototype subsystem is planned for 1986.

Talon Gold

JPL is providing support to the Air Force Space Division team that is managing Talon Gold, an experimental program for the development of acquisition, tracking, and pointing technology for potential military and civilian use. This past year, JPL assumed a key role for the Space Division in managing the major contracted effort for Talon Gold. JPL also conducted system- and subsystem-level analyses and provided experts in optics, controls, and other related disciplines.



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Energy and Technology Applications

The application of JPL's technological skills to the solution of problems in the public sector has long been an important aspect of the Laboratory's activities.

Part of this work is sponsored by NASA in the interest of technology transfer and the "spinning-off" of space research to applications on Earth. But a great deal more of such work is supported by funds made available through the NASA contract by other federal agencies—principally the Department of Energy, the Department of Transportation, and the National Institutes of Health—and by industrial associations and individual industrial concerns.

One can trace the buildup of the Laboratory's work in energy and technology applications—or what is known today as the Civil Programs—back to the 1970s. The particular concern then was "the energy problem," and the search for alternatives to fossil fuels. The Laboratory's efforts in the civil sector grew to encompass air-traffic control, biomedical technology, and industrial processes, as well.

This work is less of a departure from JPL's best known roles, in rocketry and deep-space exploration, than might be apparent at first glance.

Historically, the Laboratory has moved into progressively more complex systems over the years: rocket propulsion in the 1940s, guided-missile systems in the '50s, and space-flight projects starting in the '60s. The same systems approach that JPL employed in those pursuits found a natural extension and new challenges in civil applications in the '70s.

JPL brought to this work mature skills and an ability to solve problems within an objective framework, made possible by the Laboratory's affiliation with Caltech and the lack of connection with any commercial interests. This combination of attributes enabled JPL to make significant advances in such fields as solar photovoltaics and electric and hybrid vehicles, and to forge a new tradition in the civil sector that continued into the 1980s.

Several factors, however, have brought changes to the Civil Programs during the past year: reduced federal priorities in energy; the consolidation of JPL tasks with those of other centers working for the Department of Energy; and restraints on the Laboratory's growth caused by increasing responsibilities in space and defense and by the practical limits of current facilities.

The net result is a decidedly smaller effort in Civil Programs over the next five years, but one that retains the promise of making further significant contributions to the public good.

Alternative Energy

Energy Systems Technology

JPL researchers are investigating advanced technologies aimed at more effectively controlling electric power systems and at facilitating the integration of new energy sources.

Under one new Department of Energy effort, JPL is exploring the use of optical fibers in electric utilities, where their insensitivity to electric fields is potentially very valuable. Four areas are being studied analytically and experimentally: communications through optical fibers, power transfer through the fibers, sensing (such as measuring electric fields), and optical data processing (specifically, in the analysis of internal transformer faults).

In one of the more interesting studies in power transfer, light at a single frequency was converted to electricity by means of a laser impinging on a specially designed silicon photovoltaic cell. The cell, produced in JPL's photovoltaic laboratory, achieved a 38 percent conversion efficiency at the wavelength chosen.

In one energy study, laser light impinges on a solar cell and is converted directly to electricity.

Photovoltaics

The objective of the Flat-Plate Solar Array (FSA) project is to foster the development of technology that will permit the economical generation of large quantities of electricity using photovoltaic units. After nine years, FSA-sponsored efforts by universities, industry, and various laboratories have resulted in visible evidence of the long-range potential of this evolving technology.

Researchers are making continuing progress in their attempts to manufacture the inexpensive, high-purity silicon required for mass-producing photovoltaic cells. They have, for example, essentially completed development of a process for manufacturing highly purified silane gas, which can be converted to crystallized silicon for solar cells.

One FSA-sponsored effort at the Union Carbide Corporation involves pyrolysis of silane to silicon in a 6-inch-diameter fluidized bed reactor (FBR). The reactor was operated consecutively for periods of up to 45 hours. At JPL, an advanced FBR of the same diameter successfully demonstrated a silicon deposition process that uses higher concentrations of silane; higher concentrations produce purer crystallized silicon. Indications are that this technology will permit cost goals to be met.

A second silicon refinement method using dichlorosilane was successfully developed with the Hemlock Semiconductor Corporation. That company's work on the last major problem—the deposition of silicon in a cold-wall reactor—indicated that with optimization of reactor operating conditions, the deposition-rate goals are attainable with large reactors.

In another effort, the growth speeds of dendritic-web silicon ribbon have been increased 60 percent by the use of dynamically controlled thermal elements in the ribbon grower. Cost analysis indicates that with continued evolution, this technology could potentially lead to economic photovoltaic central-station power plants.

A JPL reactor converts silane gas to crystallized silicon for potential use in solar cells. The accompanying scanning electron microscope pictures show how crystals produced at different temperatures differ in terms of surface morphology.

FSA researchers also demonstrated the ability to accurately model, analyze, and predict the production costs of modules with single-crystal silicon solar cells. A 1980 forecast of possible production technologies and module prices in 1982 was substantiated, for example, when a Sacramento utility was able to purchase 1 megawatt of photovoltaic modules for $4.95 per peak watt of electrical output.

Module lifetimes have increased from about one year in 1975 to an estimated 10 years for 1983 modules. During that same period, module prices (in 1983 dollars) dropped from $75 per peak watt to just under $5 per peak watt.

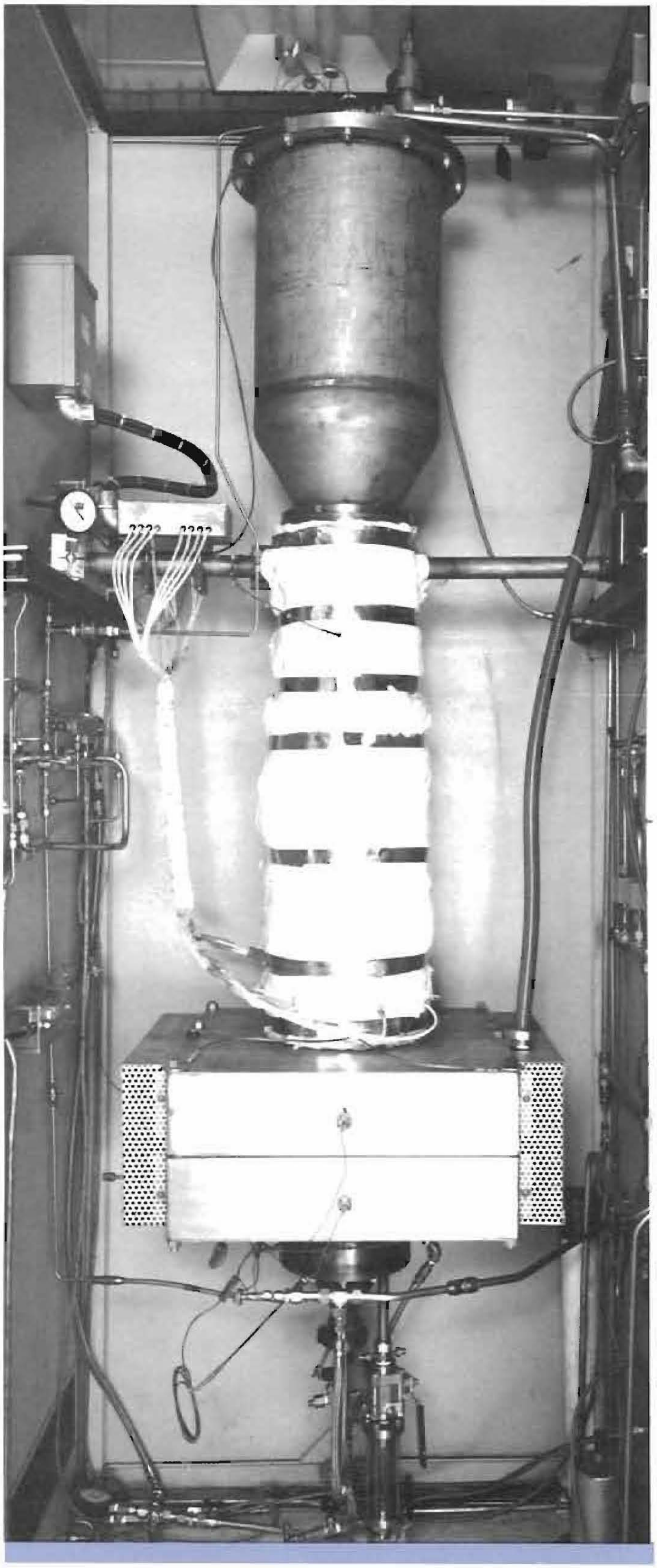
Despite progress through year's end, there remains a continuing need for advances that will lead to modules that cost still less, are more efficient, and have at least 30-year performance lifetimes.

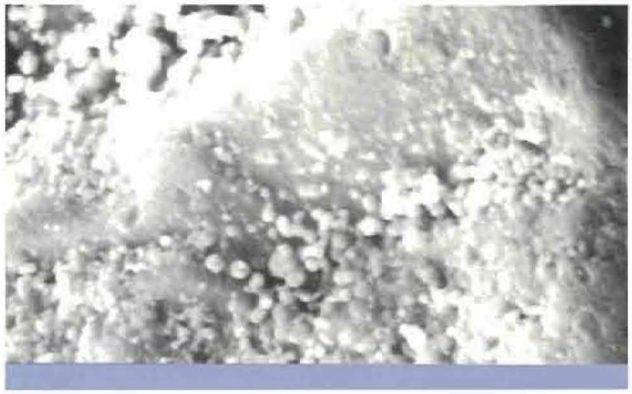
Solar Thermal Power Systems

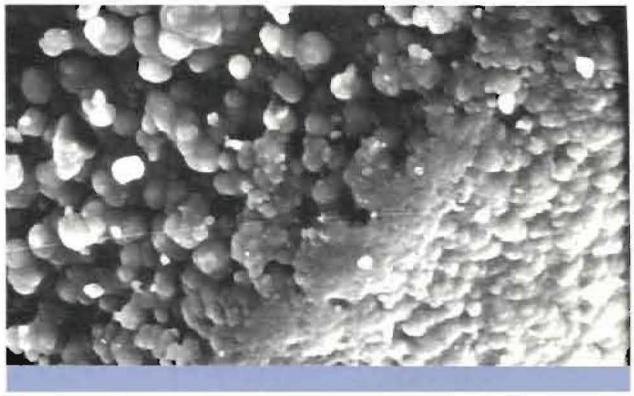
The first entire dish module designed for commercial production was installed and began undergoing testing in 1983 at Southern California Edison Company's Santa Rosa substation in Rancho Mirage.

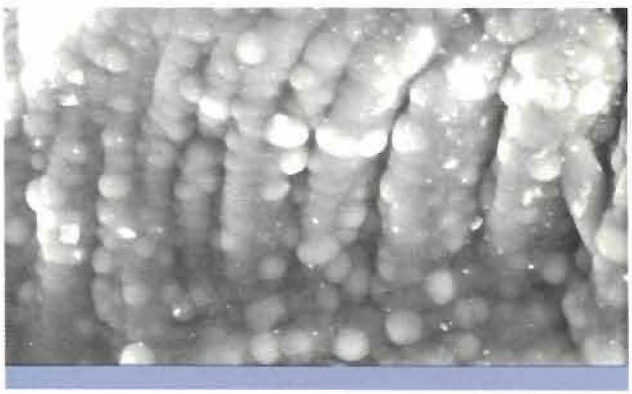
It is one of three solar-thermal power systems being developed by JPL to convert the sun's energy directly to heat or electricity. The designs combine parabolic dish receivers with engines employing different cycles.

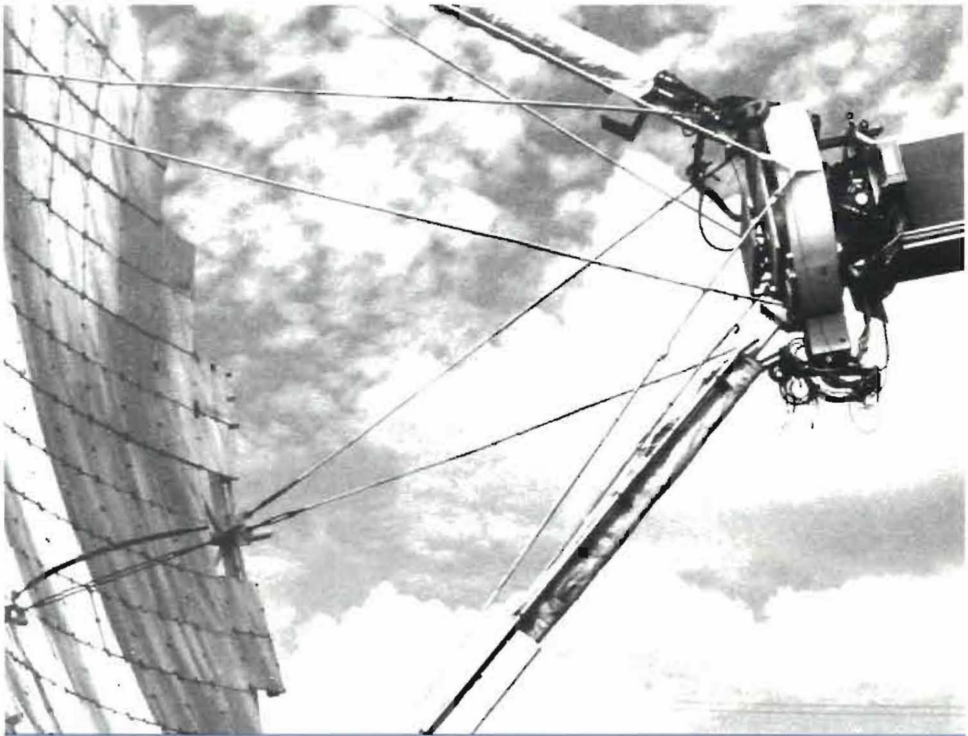
The module in place at Rancho Mirage uses a heat engine/alternator and receiver that in 1982 had demonstrated an efficiency higher than any other solar conversion system. It uses an adaptation of the JPL test-bed concentrator, which was improved and redesigned for lower production cost.











Desert clouds create a curved panorama against the highly polished mirrored surface of a solar concentrator at JPL's Edwards Test Station.

A second system under development is an organic Rankine-cycle heat engine that uses toluene as a working fluid and produces electricity by means of a permanent magnet alternator mounted on the turbine-pump shaft. It underwent testing in various attitudes at the engine fabricator's plant. The tests also marked completion in development of the hydrodynamic bearings, which offer extended, low-maintenance life. The associated parabolic-dish concentrator has fiberglass-reinforced panels and an aluminized reflecting surface; it was evaluated at JPL's test site.

Design of a dish module using a third engine cycle (an air-Brayton) was also completed in 1983. This module uses a solar adaptation of an engine developed for the Gas Research Institute to drive a heat pump. It is about half the size of the two other modules and uses a concentrator developed by private industry.

These dish modules are prototypes for potential use in 100-kilowatt solar dish experiments in Osage City, Kansas, and Molokai, Hawaii, as well as in other initial dish locations.

Biocatalysis Research

JPL researchers in biocatalysis science are focusing on resolving the basic technical barriers that have impeded the use of continuous biochemical production processes. One goal is to define improved design standards for biocatalyzed production processes.

The project is supporting applied research and development aimed at establishing the technology base that the chemical process industry will need to develop cost-competitive products based on renewable energy sources.

To date, the project has worked closely with industry, academia, and other government programs to define the major technological barriers and research "voids" in biocatalysis. Among accomplishments in 1983,

☆ Researchers developed a laboratory technique for determining the amount of biocatalyst contained in a living microorganism. The technique may eventually lead to a method for monitoring the status of biocatalytic activity in industrial-scale continuous-fermentation production processes.

☆ Modelers formulated systems that can predict the impact of genetically engineered traits and cell-regulatory techniques on protein production in microorganisms. Refined versions of these models may one day be used to design optimal fermentation vessels and control strategies.

☆ The economics and energy requirements for an industrial butanol–acetone fermentation process were analyzed as a baseline for setting priorities for future biocatalysis research and development needs. Analysis has indicated that a biocatalyzed-based butanol production process would use 30 percent less energy than a conventional process and could decrease the selling price of butanol by 20 percent.

☆ Preliminary data were generated to help describe the mechanisms by which microorganisms convert biomass into useful chemicals.

In the coming year, the project looks forward to initiating a series of competitive research contracts to begin developing the technology base for biocatalyzed chemical production processes. New knowledge will flow directly to industry by means of a cooperative industry–university–government research group that the project plans to establish.

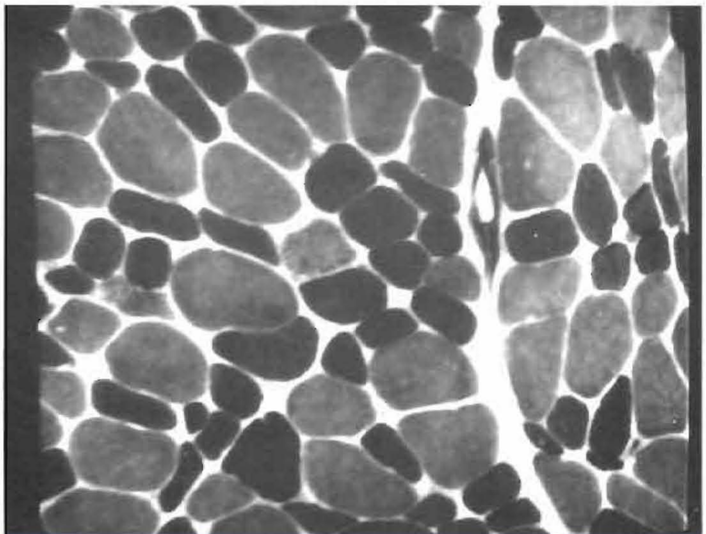
Spectroscopy in Chemical Sensing

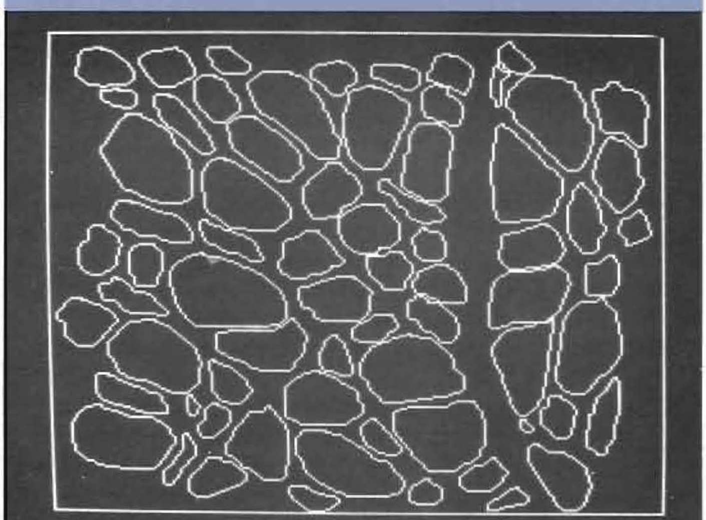
JPL is investigating the use of thin-film chemical sensors based on electron-tunneling spectroscopy. Such devices could fill the considerable need for a lightweight, sturdy electronic chemical sensor in industrial applications.

The devices are simple metal–insulator–metal tunnel junctions—for example, aluminum–aluminum oxide–gold—fabricated by the evaporation and oxidation of base metals in an oil-free, ultra-high-vacuum system.

Intrinsic surface states have been observed on the surface of gold film at room temperature by means of electron-tunneling spectroscopy. Electrons in surface states are confined only to the metal surface and hence permit extremely sensitive inspection of the chemical environment of the surface. This research offers a potential mechanism for a new type of ultrasensitive solid-state thin-film chemical sensor.

JPL researchers are designing techniques for automated muscle biopsy analysis. Muscles are cut in cross sections to reveal individual fibers under the microscope (top picture); a computer then locates, outlines, numbers, and measures the fibers, to produce the second image.





Biomedical Technology

Deep Arterial Lesion Ultrasound Imager

JPL has developed a new medical ultrasound instrument for the National Institutes of Health that can image deep-lying arteries. The device is designed for noninvasive detection and imaging of atherosclerotic plaques, allowing doctors to follow plaque progression and regression in size and shape.

The scanner is able to resolve the inside and outside of a 1-millimeter arterial wall at a depth of 7.3 centimeters in the tissue. The depth performance is more than twice that achievable with existing commercial imagers that use pulse-echo techniques.

Fluid Shift Measurement

An observed effect of microgravity on the human body is a shift of fluids from the lower to the upper body. As part of a study of the physiological consequences of this effect, JPL researchers are developing a technique to measure fluid loss in the legs during weightlessness.

The method, developed jointly with Johnson Space Center, involves computer analysis of leg photography taken before, during, and after the seventh and eighth space shuttle flights. Because the computer can measure a larger number of points along the leg, as compared to direct measurement, this method has the potential for substantially greater overall accuracy.

Fluid Dynamics

JPL, working with the University of Southern California School of Medicine, carried out a quantitative investigation of the fluid dynamics of arterial flow. Particular focus was placed on branch regions, since atherosclerotic lesions often occur at these sites.

Pressure measurements and flow visualization results were obtained in hollow vascular replicas made from primary casts of human cadavers. The data revealed the complicated nature of branch flows that involve three-dimensional motion, increases in pressure, and local flow-separation regions. Flow separations tend to occur when the pressure rise is large enough, and such regions seem to be intimately associated with the atherosclerotic process.

Environmental Technology

Toxic-Waste Disposal

JPL completed a study to identify and select novel, safe, cost-effective concepts for disposing of hazardous chemical munitions for the U.S. Army Toxic and Hazardous Materials Agency. Of 58 novel concepts studied, four were developed into complete processes, with estimated life-cycle costs three to six times less than those of current combustion technologies.

According to the study, significant savings would result from maximum use of automated processes, use of transportable disposal facilities that could be moved to different locations for on-site disposal, and designs that keep reactor volume as small as practical (thus minimizing containment cost and the danger of human exposure).

The stress on cost and safety as the two critical parameters led to an unexpected result: the discovery that an explicit consideration of safety during early conceptualization of the processes often produced lower overall costs.

Aviation

National Airspace System

The Federal Aviation Administration (FAA) has begun an extensive, multibillion-dollar upgrading of its entire National Airspace System (NAS),

The Voice Switching and Control System will provide better communications for air-traffic controllers. JPL and TRW are working on the system for the Federal Aviation Administration.

which regulates air-traffic operations around the country. The agency has asked JPL to perform project-definition activities for two NAS subsystems.

One is the Central Weather Processor (CWP), a data processing and display system whose goal is to improve safety and efficiency through the rapid dissemination of weather information to controllers and pilots.

The CWP will maintain an extensive base of graphic and alphanumeric meteorological data, including information from satellites and radar. National Weather Service meteorologists will be able to use interactive computer workstations to call up data for improved weather forecasts. Designers are making the CWP expandable in size, capability, and number of system elements, in anticipation of future demands.

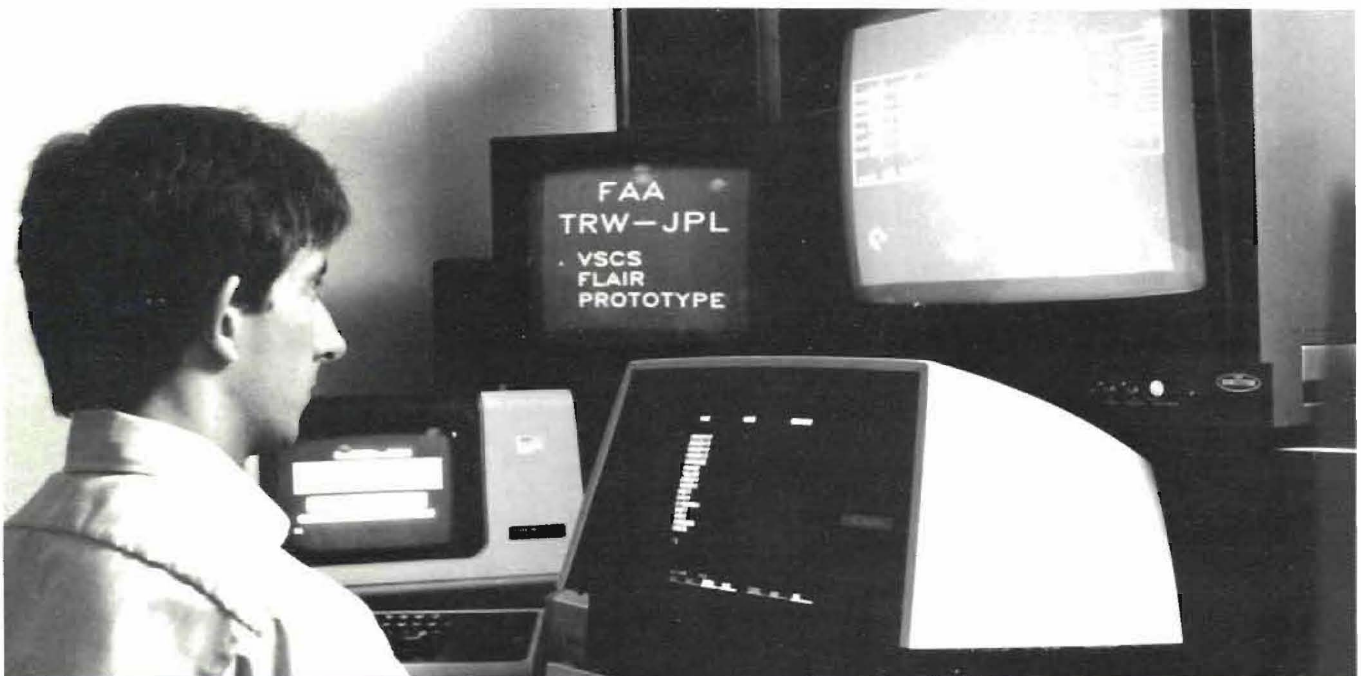
The second project is the Voice Switching and Control System (VSCS), which will provide integrated radio and telephone/intercom services for the FAA's Area Control Facilities. Touch panels will be integrated into the traffic controllers' sector suite consoles. The computerized system is also expandable in size and capability.

In both cases, JPL will contribute its experience in developing highly reliable and flexible computer-based systems. The efforts require extensive interaction with system users, careful systems engineering, and the latest in software development methodology.

Other Aviation Studies

JPL also assisted the FAA with 1) the development of the Weather Message Switching Center Replacement, a digital communications hub for forecasts emanating from the Weather Service's National Meteorological Center; 2) a study of a low-cost method of calibrating the agency's new microwave landing system technology; and 3) a study of the applicability of satellites to helping locate aircraft independently of the onboard navigation system used.

Work continued, as well, at JPL's Aircraft Fire Test Facility, where investigators studied cabin fire hazards and, in particular, the effects of winds and interior materials on postcrash fires.



TRW DEFENSE SYSTEMS GROUP

Institutional Activities

Research and development costs for the fiscal year ending in September 1983 were $421 million, an 8.5 percent increase from fiscal 1982.

Costs for NASA-funded activities rose 4.1 percent, to $331 million. Energy and Technology Applications costs declined to $40 million, down 11.1 percent from the previous year, while tasks for the Department of Defense amounted to $48 million, an increase of 118.2 percent.

The JPL workforce increased during the year from 4,590 to 4,907. The figure for 1981 was 4,778.

After nearly 20 years of operation under Contract NAS7-270(F)—under which government facilities were provided to the Laboratory for its research efforts—Contract NAS7-920(F) was executed as a replacement.

Procurement obligations during fiscal 1983 totaled $211 million, representing a 1 percent decrease from the previous year. The total included nearly $194 million to business firms. Of that, obligations to small business remained constant at 38 percent; at the same time, obligations to minority business increased from 4.8 percent to 5.2 percent.

Discretionary Funds

Twenty-three new tasks received support from the Director's Discretionary Fund in 1983, while seven continuing tasks received second-year increments. The fund provides resources for independent research and development in promising areas of science and engineering. It makes possible support of innovative and seed efforts for which conventional funding is not available, and it encourages collaborative work with university faculty and students. The current funding level is $1 million per year. Tasks are selected from about 100 proposals considered annually; the typical award is about $30,000 to $50,000.

In addition, sixteen tasks were initiated with support from the Caltech President's Fund, a second source of discretionary funding. It is intended specifically to support JPL research collaborations with the Campus and other universities. NASA contributes $350,000 each year on a matching basis. Other participants in the new and continuing funded tasks were the University of Arizona, the University of Chicago, the University of Southern California, Arizona State University, John Brown University, Stanford University, the Massachusetts Institute of Technology, and four campuses of the University of California.

NASA Honor Awards

The NASA Honor Awards program gives special recognition to outstanding individual and team efforts. Thirteen JPL individuals and five groups won awards in 1983:

NASA Outstanding Leadership Medal
John J. Paulson

NASA Exceptional Scientific Achievement Medal
Dennis L. Matson

NASA Exceptional Engineering Achievement Medal
Robert C. Tausworthe
Marc R. Trubert

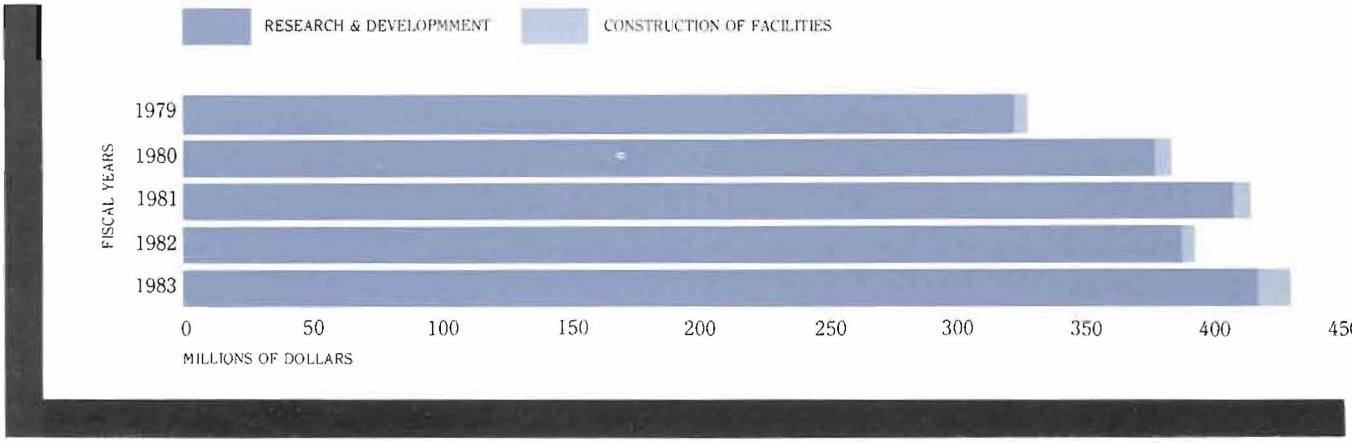
NASA Exceptional Service Medal
James W. Brown, Walter J. Downhower, Edward J. Johnston, J. Frank Jordan, Krishna M. Koliwad, Kathleen J. Lee, Robert E. Martin, James R. Stuart, and George E. Tennant

NASA Group Achievement Award
Electric and Hybrid Vehicle Project Team, Mobile Radio Frequency Interference Surveillance System Implementation Team, ORION Project Mobile Antenna System Implementation Team, Solar Mesosphere Explorer Project Staff, Viking Lander 1 Recovery Team

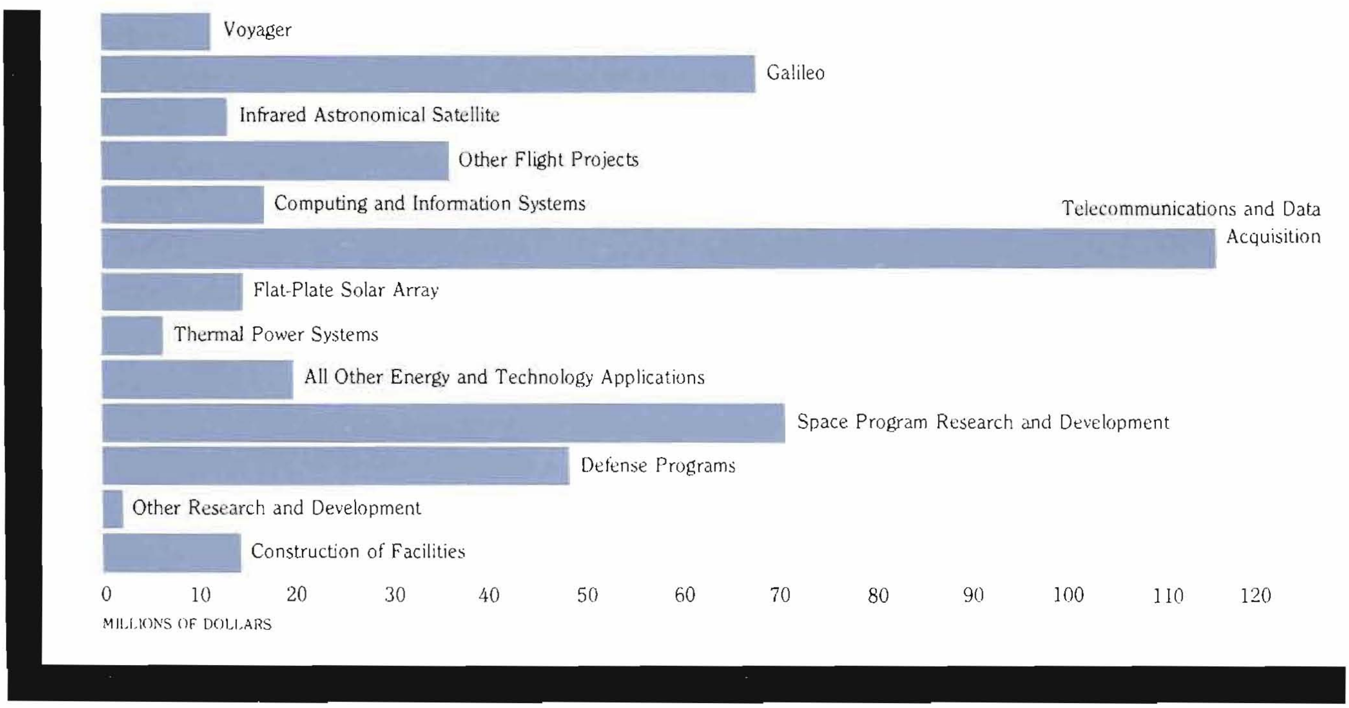
Visiting Scientists

Participants in the Distinguished Visiting Scientist program, which was initiated in 1979, continued to provide short-term consultation on important JPL projects. Participants in 1983 were Professors Michael Longuet-Higgins of England; Jacques Blamont and Ichtiaque Rasool of France; Hugo Fechtig and Klaus Hasselmann of Germany; Syun Akasofu, Richard Goody, Peter Niiler, and David Turnbull of the United States; and the late Guiseppe Colombo of Italy.

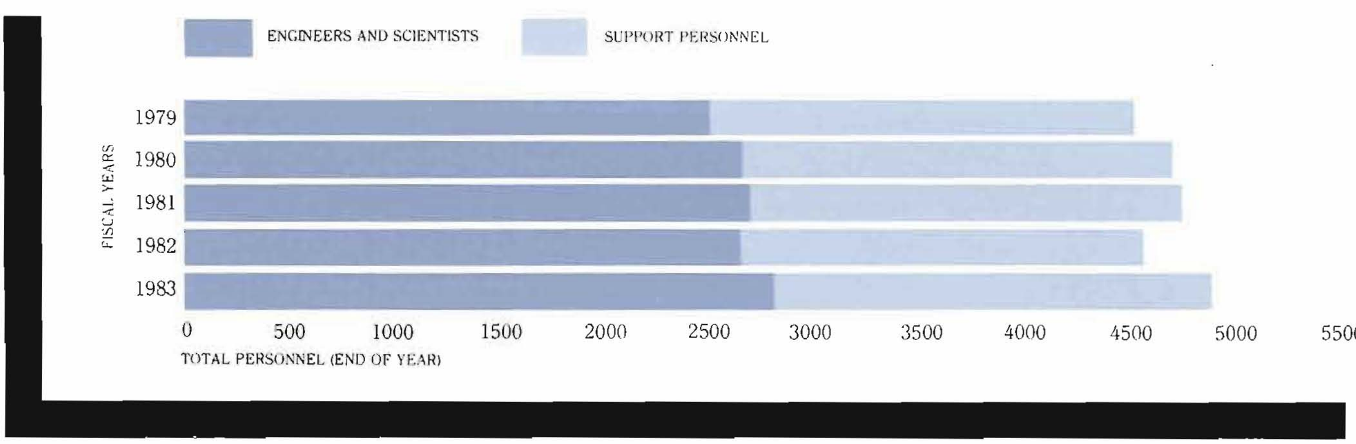
Total Costs



Fiscal Year 1983 Costs



Personnel



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JPL 400-236 6/84